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MONTANA WIND ENERGY RESEARCH AND DEVELOPMENT PROGRAM

Prepared for

MONTANA DEPARTMENT of NATURAL RESOURCES and CONSERVATION

MONTANA WIND ENERGY RESEARCH AND DEVELOPMENT PROGRAM

Prepared by

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32 South Ewing, Helena, Montana 59620
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1.0 OBJECTIVE

The objective of the Montana Wind Energy Research and Development program as initially proposed was to purchase, install, demonstrate, and monitor a 20 to 40 kW wind turbine generator in the Whitehall area and a monitoring tower in the Livingston and Whitehall areas. Wind data could then be collected at both Livingston and Whitehall while simultaneously generating electricity at the Whitehall site. The measured data could be compared to the actual generation data, and correlations could be developed that would indicate generating capability at Livingston. The results would be an economic analysis of cost per kilowatt hour of electricity and a technical analysis of wind-generated electricity and its importance to the utility grid system.

However, some problems developed early in the program to obstruct the primary objective. First, the intended site for the wind generator, the Daisy Brazier Boys Ranch near Whitehall, was closed following an investigation by the state. This closure necessitated locating another generating site. Second, when the Montana Department of Natural Resources and Conservation (DNRC) made the award to the Montana Energy and MHD Research and Development Institute (MERDI), they specified that MERDI use a wind turbine generator that was being developed by a previous grantee, Independent Power Developers, Inc. (IPD) of Noxon, Montana. It became apparent that IPD could not deliver the wind turbine generator in time to be used for this program. Thus, late in November 1979 permission was given MERDI to purchase an alternative system. After reviewing the budget, MERDI made a request to the Montana Power Company (MPC) to purchase a wind turbine generator that could be installed in the MPC system at a site

near Livingston. The MPC response was positive and they purchased a 25 kW wind turbine system from Jay Carter Enterprises of Burkburnett, Texas.

MERDI was given permission to utilize data from the generator for this program. Third, it was further decided to install three monitoring towers for wind data gathering instead of the two that were originally planned. MERDI then purchased and installed 10 meter (33 foot) towers and monitoring equipment at Whitehall, Livingston, and Big Timber, Montana.

After these initial problems were overcome, the program was restructured and new objectives defined. MERDI accomplished the following objectives:

1. Selected three wind monitoring sites for installation of 10 meter towers and the described recording devices;
2. Arranged for the purchase of a 25 kW wind turbine generator for MPC and installed it at Livingston;
3. Monitored and collected data at all three sites (Livingston, Whitehall, and Big Timber);
4. Compared measured generator output to theoretical calculated output based on wind data; and
5. Correlated data between the three sites and predicted the value of wind-generated electricity at all three sites.

The five objectives listed above were completed and a detailed discussion of each one is presented in subsequent Sections of this report.

2.0 PROJECT IMPLEMENTATION

Implementation of this project progressed as scheduled, once the previously discussed setbacks were resolved.

2.1 Project Planning and Equipment Acquisition

For purposes of this report, this section is divided into three subsections: 1) project planning; 2) wind monitoring equipment; and 3) wind energy conversion equipment.

2.1.1 Project Planning

The original project plan proposed to DNRC encompassed a nine-month project with a six-month data collection and correlation period. A 20 to 40 kW wind turbine generator was to be installed at the Daisy Brazier Boys Ranch near Whitehall, Montana, and two 120-foot monitoring towers would have been installed near Whitehall and Livingston, Montana. At the time of grant award in June 1979, DNRC requested the use of a 25-kW wind turbine generator that was being developed by Independent Power Developers of Noxon, Montana under a previous grant. The IPD system was not completed at that time and it became apparent that delivery would be too late for use in the program. Finally, in November of 1979, a meeting was held in Helena between IPD, DNRC, and MERDI concerning the wind turbine generator. As a result of that meeting, permission was granted to reschedule the project, re-examine the budget, and purchase a different wind turbine generator.

From that point in time, a new program plan was developed as shown in the milestone chart of Table 1. This new planning schedule included the purchase and installation of a wind turbine generator and the installation of three 10-meter monitoring towers. Also, it became obvious that sufficient funds were not available to purchase a 25 kW wind turbine generator. Following discussion with DNRC, project personnel contacted Montana Power Company (MPC) and asked if MPC would purchase a wind turbine generator system that could be installed directly on the MPC grid and be monitored for this project. MPC had originally agreed to provide $10,000 cash and $5,000 in engineering time, to the project. At this time MPC agreed to provide a total of $25,000 to the project in order to purchase the system. Subsequently, it was decided that the site for the wind generator would be in the Livingston area. Livingston is a known high wind area and MPC has transmission and distribution lines nearby which could be tapped into. From this point on, it was simply a matter of selecting equipment and systems and following through with the program schedule.

2.1.2 Wind Monitoring Equipment

For the past five years, project personnel were involved in monitoring wind and air quality as part of the MHD project in Butte and have experience with equipment similar to that which was used in the project. During these past programs, Campbell Scientific Corporation equipment was found to be superior in quality and performance; therefore, similar equipment that was compatible with the computer and interface equipment was purchased (see Appendix A).

PROJECT MILESTONE CHART

PROGRAM: MONTANA WIND ENERGY R & D PROGRAM

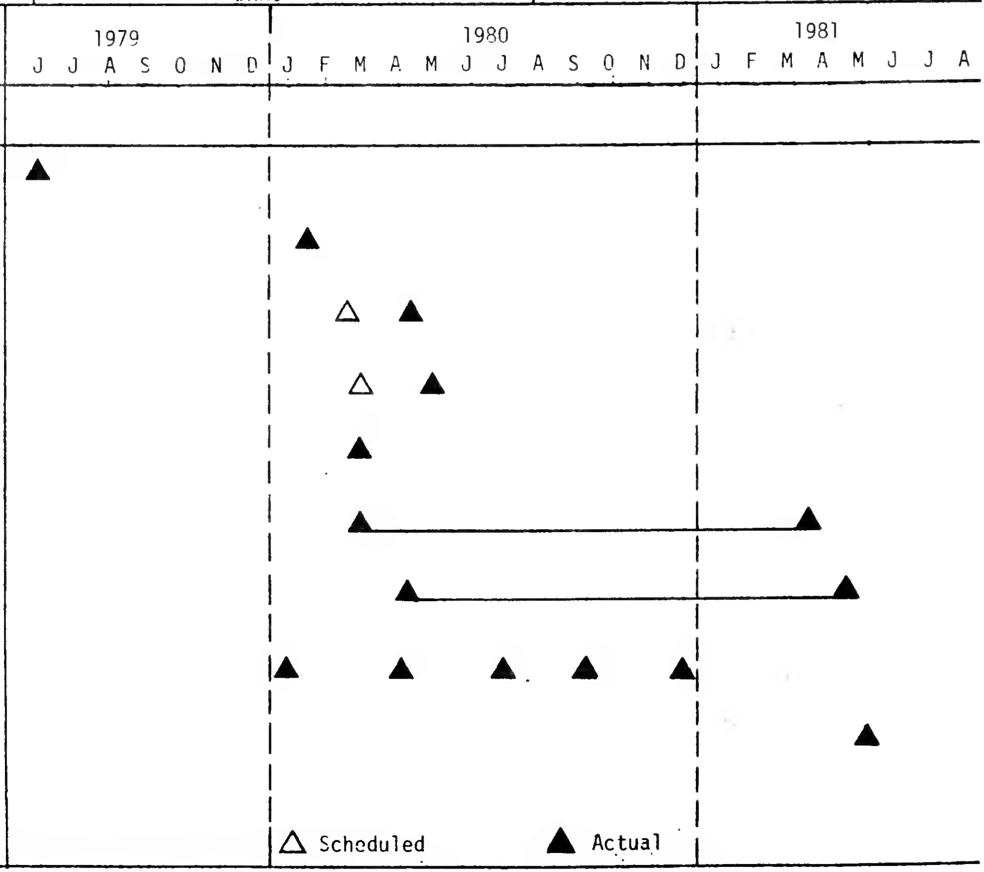
CONTRACT NO. 203-782

VENDOR DNRC

TITLE: PROJECT SCHEDULE AND MAJOR GOALS

MAJOR MILESTONES AND DECISION POINTS

1. Project Initiation
2. Purchase New SWECS
3. Delivery of New SWECS
4. Installation of SWECS
5. Erect and Start-up Monitoring
6. Operation and Data Acquisition
7. Data Reduction and Correlation
8. Quarterly Reports
9. Final Report



At each of the three wind monitoring sites, the following equipment was installed:

1. Triex (10 meter) Tower MW 33
2. Guy Kit MWK 1
3. Microprocessor CR 21
4. Cassette Recorder RC 235 (4)
5. Velocity Sensor 014A
6. Direction Sensor 024A
7. Cross Arm (4 1/2 ft) 019
8. Temperature Sensor 101 and Shield 041
9. Instrument cable to connect Sensors to the CR21
10. Recorder/CR21 Cable SSC235

This equipment was purchased through Campbell Scientific Corporation based in Logan, Utah. The CR21 Microprocessors had to be programmed to perform the functions necessary for data acquisition (see Section 2.2 for a detailed discussion).

2.1.3 Wind Energy Conversion Equipment

Under terms of the agreement with DNRC, three commercial manufacturers of wind energy conversion systems (WECS) were identified as potential suppliers of an acceptable wind energy conversion system. Three machines were available:

1. Carter Wind Generator, Model 25;
2. Mehrkam Energy Development Company, Model 440; and
3. Wind Power Systems, Inc. Storm Master Model 10-18-1G-3P-60.

Brochures describing these units were provided in the December 1979 quarterly report to DNRC.

Simultaneously with identifying existing systems, it was determined that the project budget was not sufficient to cover the purchase of a wind energy conversion system and also provide the degree of monitoring required. Following approval from DNRC, MPC was approached with the suggestion that MPC provide additional funds for purchase of the WECS. MPC would then own the WECS and connect it into their electric grid system while MERDI would monitor the performance as part of the contract requirements to DNRC. MPC agreed to purchase a WECS with MERDI acting as purchasing agent. The project then became a cooperative one between a state agency (DNRC); a public utility (MPC); and a private research and development institute (MERDI).

Study of available information on existing commercial units by MPC, DNRC, and MERDI determined that the Carter Model 25 was the best unit for the program. Carter Manufacturing in Burkburnett, Texas was visited and a Carter Model 25 observed in operation. The unit was purchased with a tentative delivery date scheduled for late March or early April 1980. The Model 25 was delivered and installation completed on May 2, 1980.

2.2 System Installation

Under terms of the program, four separate systems were installed. Wind monitoring systems were installed at Whitehall, Big Timber, and Livingston; the wind energy conversion system was also installed at Livingston. Each of

the four systems operated independently of the other three. Each system had its own peculiarities; thus each one will be discussed separately.

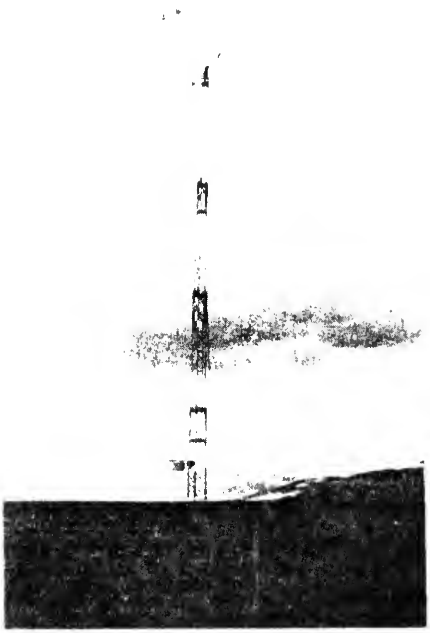
Prior to the installation procedure, programs that would convert electronic signals generated in the sensors to audio signals recorded on magnetic tape were developed for the CR21 microprocessor. Appendix A contains a copy of the program developed for data acquisition at each monitoring site. After data were collected on magnetic tapes, they were read into the computer using an interface instrument called a "gold box." The gold box converts the audio signal from the tape into computer language; then another of the prepared computer programs prints the data into the final format, as presented in Appendix C (separate document).

2.2.1 Whitehall Monitoring Tower Installation

The first monitoring tower installed on February 6 and 7 (1980), was located near Whitehall, Montana. The site was approximately four miles west of Whitehall. The exact location of the site is on the northeast corner of the northwest 1/4 section of Section 12, Township 1 North, Range 5 West in Jefferson County. Figure 1 offers views of the Whitehall site from two different angles and shows the tower and instruments in place.

The entire installation was completed in less than two days. The tower, a 10-meter (33-foot) telescoping model, was installed on a concrete base. The base was initially poured indoors and transported to the site by truck. A metal base plate with three threaded bolts for mounting the

Looking North



Looking Southeast

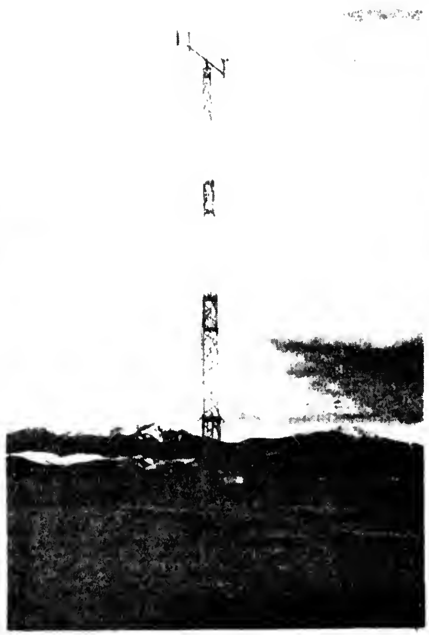


Figure 1.--Whitehall Monitoring Site

tower was embedded in the concrete base as it was poured. At the site the concrete base was positioned and leveled for the tower.

This particular base measured two feet by two feet by one foot thick and was quite difficult to handle. Three holes at least three feet deep were then dug by hand labor for the three anchor rods. The three holes were positioned 12 feet out from the tower base and were located in a radial pattern. A gasoline driven, hand-held, post-hole digger proved ineffective in the rocky ground. Digging of these three holes proved to be the single most time-consuming and laborious effort in erecting the monitoring towers. The fact that the ground was frozen solid for most of the needed depth also complicated the work. Digging each hole required from one-and-one-half hours to two hours.

Upon completion of the holes, the anchor rods were twisted into place in the earth as far as they would go and earth was tamped firmly around the anchors.

The anchor rod holes were positioned in triangular fashion around the base plate with one anchor upwind, in the direction of the prevailing wind. This procedure was recommended by the manufacturer to insure proper tower support in the prevailing wind direction.

The procedure for erecting the 200-pound tower began with cutting the guy cables to proper length and attaching them to the tower. The 12-foot fully retracted tower was then bolted to its base plate which had been previously bolted to the square concrete base. Two men pushed the retracted

tower into a vertical position with the tower pivoting up on its hinged pin in the base plate. One man steadied the vertical tower and the second man secured all of the cables into the eyes of the anchor rods using turnbuckles for tension adjustment. The crank and winch used to extend the telescoping tower to its full height were then attached.

Instruments were now installed on the tower as part of the activation procedure. The wind direction sensor and the wind velocity sensor were installed on the four-and-one-half foot cross arm that had not yet been mounted on the tower. Cables that would extend to the ground when the tower was raised to its highest position were attached to each sensor. The cross arm and sensors were then attached to the top of the tower with the cross arm and direction sensor pointing in the direction of true North for proper orientation.

The tower was cranked up to its full height of 33 feet with the sensor cables hanging down. Then the temperature sensor and its shield were attached to the tower at about six or seven feet above the ground. The instrument box/enclosure was bolted to the tower at about three to four feet above the ground. The sensor cables were routed into the enclosure and attached to the CR 21 microprocessor. The CR 21 microprocessor was then energized and programmed as illustrated in Appendix A.

A connector cable was attached between the CR 21 and the cassette recorder and the recorder was energized, thus making the monitoring system operational. A three-strand barbwire fence was installed around the tower to exclude cattle and other large animals.

No major problems were encountered during this installation at the Whitehall site. The manual labor of digging anchor rod holes in frozen ground was the most troublesome job. The installation including the operational startup required less than two full days.

2.2.2 Big Timber Monitoring Tower Installation.

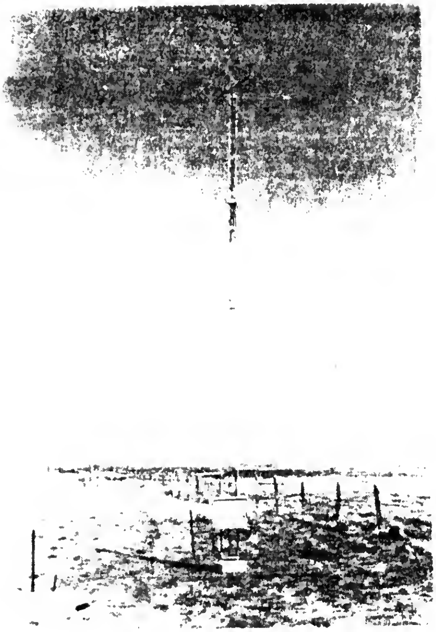
The second monitoring tower was installed near Big Timber, Montana on February 18 and 19 (1980) at a site approximately four miles east of Big Timber. The exact location of this site is on the northeast corner of the southeast 1/4 section of Section 8, Township 1 north, Range 15 East in Sweet Grass County. Figure 2 presents photographs of the Big Timber site from two different angles and shows the tower and the instruments in place.

Installation of the monitoring equipment at the Big Timber site followed exactly the same procedure used at the Whitehall site. The installation was again completed in less than two full days. Also, once again the most time-consuming effort was digging anchor rod holes in frozen ground. Overall, no major problems occurred during the installation, and the station was put into operation at that time.

2.2.3 Livingston Monitoring Tower Installation

The Livingston monitoring site presented some problems in obtaining legal access and subsequently in reaching the site. Project personnel had negotiated with the City Council and County Commissioners to place

Looking Northeast



Looking East

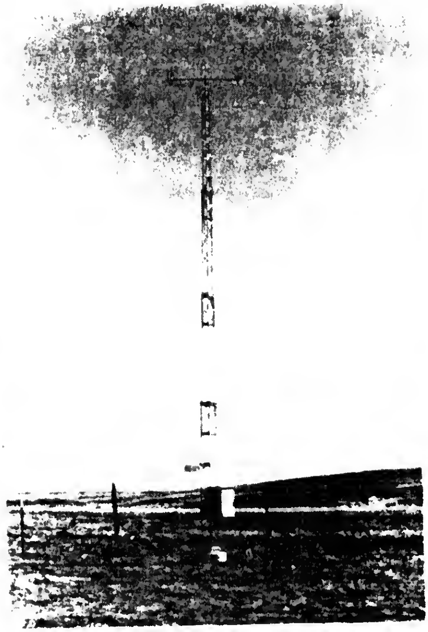


Figure 2.--Big Timber Monitoring Site

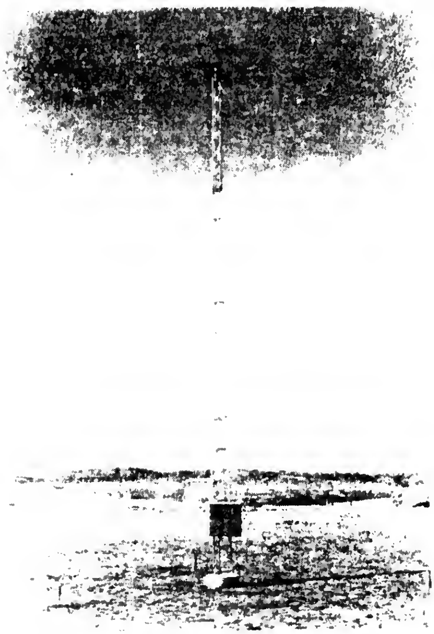
the monitoring system on the old airport site which eventually had to be abandoned due to difficult access. Permission had been given verbally, but as late as February 1980, written authorization to make the installation had not been received. In the meantime, blowing snow had closed the only access road to the site where the tower and concrete base now lay buried under snow.

Project personnel searched the general area for other means of access or for another site with acceptable access. Eventually, the operational site was located approximately one mile east of the old airport, on Mr. Ted Watson's property. The land had year-around access from a county road maintained by Park County. Mr. Watson took project personnel cross-country in a four-wheel drive truck to recover the stranded tower and base plate from its location near the old airport.

This tower was installed on March 10 and 11 (1980) on the Watson property approximately two miles east of Livingston. The exact location of this site is on the southwest 1/4 section of Section 9, Township 2 South, Range 10 East in Park County. The site is south of I-90 and visible from the highway. Figure 3 presents photographs of the Livingston site from two different angles which show the tower and the instruments in place.

Installation at the new site was then performed in the same manner as previously described. This site was the hardest of all three in which to dig anchor holes. A combination of frozen ground and very rocky soil necessitated lying on the ground and digging out rocks by hand. However,

Looking North



Looking Southeast

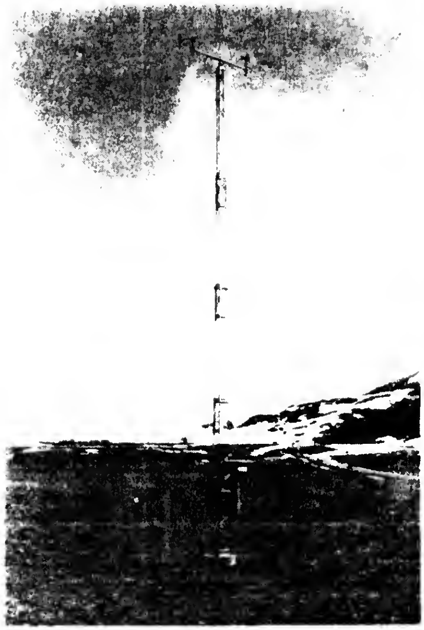


Figure 3.--Livingston Monitoring Site

the actual installation of the monitoring tower including the operational startup again took less than two full days for completion. This tower was located approximately 200 feet from the wind energy conversion system, as described in the following Section.

2.2.4 Livingston Wind Energy Conversion System Installation

The wind energy conversion system (WECS) was installed at the Livingston site on May 1 and 2 (1980) by a team of personnel from Montana Power Company, Jay Carter Enterprises, Inc., and MERDI. This site also included the Livingston wind monitoring system described in the previous Section. Prior to the actual machine installation, MPC built a three-phase feeder, or distribution, line to the site and installed a transformer to step-up the wind generator voltage to the distribution line voltage. The 240-volt, 3-phase alternating current wind generator voltage synchronizes automatically with the distribution line. MPC also had installed a control box for the interface system, used to connect the WECS with the power grid. Figure 4 is a photograph of the interface system. The interface system is used to control the operation of the WECS, and to protect the power company personnel and customers from electric shock or equipment damage due to falty operation of the WECS.

This particular interface system is comprized of five main components. These components are a manual disconnect, an automatic disconnect, an over-voltage relay, an under-voltage relay, and a metering system.

The manual disconnect is a manually operated switch and circuit breaker used to disconnect the WECS from the power grid for maintenance operations. This disconnect will also operate automatically if an over-current condition should exist.

The automatic disconnect is an electromechanically operated contactor that is operated by the over-voltage or the under-voltage relays. In the event the power line goes dead, the under-voltage relay will cause the automatic disconnect to open the circuit between the WECS and the power grid.

In the event that the power line voltage is too high, because of a power surge or a lightning strike, the over-voltage relay will cause the automatic disconnect to open the circuit between the WECS and the power grid.

The metering system is made up of two kilowatt-hour meters. One meter records the amount of electric power consumed by the WECS for field excitation. The second meter records the amount of electric power delivered from the WECS to the power grid.

During the month of July, MPC installed recording devices in the control panel to record wind machine output. That data was then fed into their computer on a regular basis to obtain computer printout, which became available August 1, 1980.

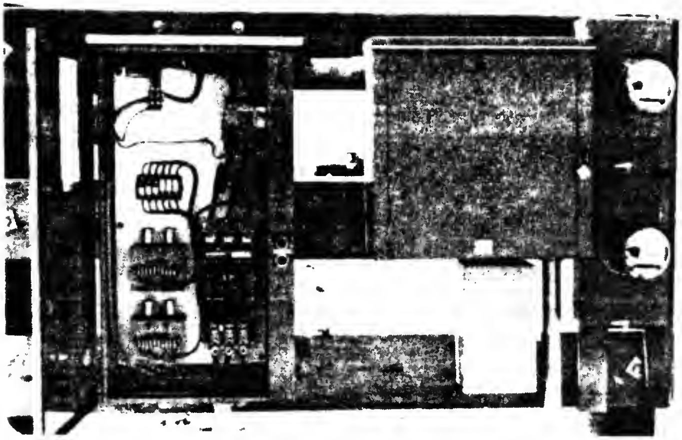


Figure 4.--System Control Box

Due to both the novelty of wind energy and the general interest of the public in wind energy conversion systems, as many as 50 people visited the site each day during the two-day installation. Of these fifty people, perhaps ten actually assisted in some aspects of the installation.

An estimate of the actual time and hours spent on the installation and start-up would be 10 people for two days, or about 160 to 180 man hours. Mr. Carter assured everyone present that his three people, professionals in the business, could have erected and started the system by themselves in about two days for a total of 48 man hours. However, as described below, such a brief installation schedule was not the case for this particular installation.

Installation of the wind energy conversion system was begun by using a backhoe to dig holes five to six feet deep, one for the tower foundation and four for the anchor rod holes. Figure 5 shows the backhoe digging one of the anchor rod holes. The holes were dug in a pattern that spaced the anchor rods at 90° angles around the tower foundation, with one anchor positioned upwind in the prevailing wind direction. After the holes were dug, rebar was placed in the bottom of the holes and through the anchor rods to insure proper rigidity. Figure 6 shows one hole with the anchor rod in place and the rebar at the bottom of the hole.

The next step was to pour cement for the anchors and the tower foundation. The tower was to be installed the following day; thus, it was necessary to order a fairly dry mixture of cement and add moisture in the form of a quick setting agent called "SEEK A SET-C." Using this method,

Figure 5.--Backhoe Digging Anchor and Foundation Holes

Figure 6.--Anchor Rod Ready for Concrete

the cement was poured on the afternoon of May 1, 1980. Prior to leaving the site that evening, the cement was already beginning to harden and the earth was pushed back into the anchor holes and excess earth was spread and leveled so that the next day could be spent entirely with installation of the tower and the wind turbine generator.

The following morning, May 2, 1980, the tower was bolted to the metal base plate which had been set in the concrete foundation the day before. As shown in Figure 7, the design of the tower includes a hinged pin in the base plate that allows the tower to be conveniently raised and lowered for easy access to the generator.

In the next step the guy wires were attached to the tower and to the anchor rods. One unique aspect of this particular system is that one guy wire is attached to the end of the gin pole which is connected to the tower. By attaching a "come-along" pulley mechanism to the guy cable and a vehicle, as shown in Figure 8, the tower can be raised and lowered by two people with a minimum of effort. Figure 8 illustrates raising the tower without the wind turbine generator attached.

The tower was successfully raised and the four guy cables properly tensioned; the next step was to lower the tower to the horizontal position and install the wind turbine generator. With the tower once again in the lowered position, the nacelle containing the generator, transmission, and electronics was moved into place over the end of the tower shaft. Figure 9 shows the wind turbine generator on the tower and also presents an internal view of the components.

Figure 7.--Tower Base and Hinged Pin

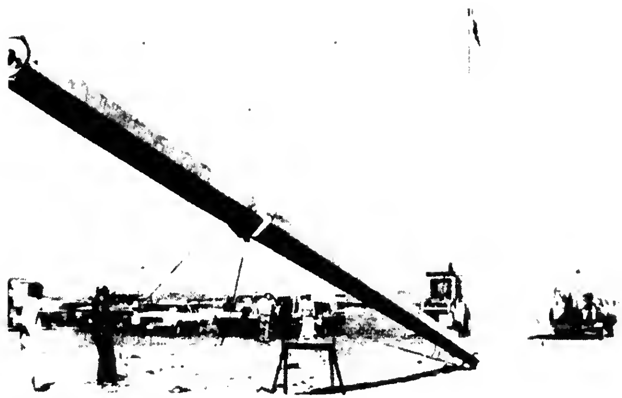


Figure 8.--Raising the Tower

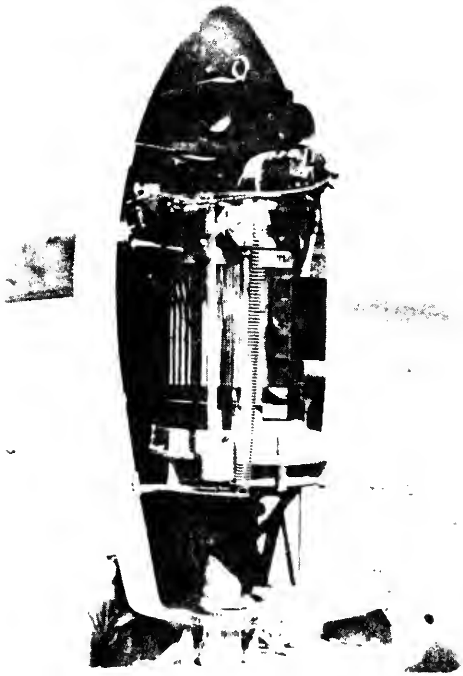


Figure 9.--Internal View of WTG

Near the top center of Figure 9 is a black control box which contains much of the control circuitry and electronics of the system. It is fairly easy to change this component, if necessary. Directly under the black box is a brush block. This component holds brushes against conducting slip rings. As the blades turn the generator, electricity is carried through the slip rings and down the center of the tower by a three-wire conductor. The electrical output is then routed from the base of the tower to the electrical interface system.

At this point, the blades were installed into the rotor hub. With each blade measuring 16 feet, diameter of the total swept area was 32 feet. The blades were then cleaned of any dirt, bugs, and grime, as shown in Figure 10. Checks for electrical continuity and other last minute details were completed and the cover bolted to the nacelle, as shown in Figure 11, with the lightning rod protruding through the top of the nacelle. Following the above checks, the wind energy conversion system was ready for operational erection of the tower and start-up of data collection.

The series of photographs shown in Figures 12, 13, 14, 15, 16, and 17 are sequential photos of the initial erection and show incremental steps in the wind energy conversion system installation. Figure 17 shows the system fully erected and ready for start-up. At this time, the only remaining steps were to remove the "come-along" pulley mechanism and attach the final guy wire to its anchor rod. The electrical switches were then activated and the brake mechanism at the base of the tower was released. However, when this start-up was completed, sufficient winds were not present to generate electricity.

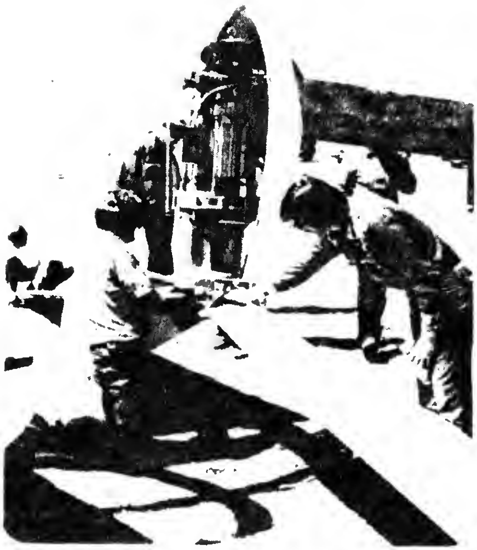


Figure 10.--Cleaning and Installing the Blades

Figure 11.--Assembled Unit Showing Lightning Rod

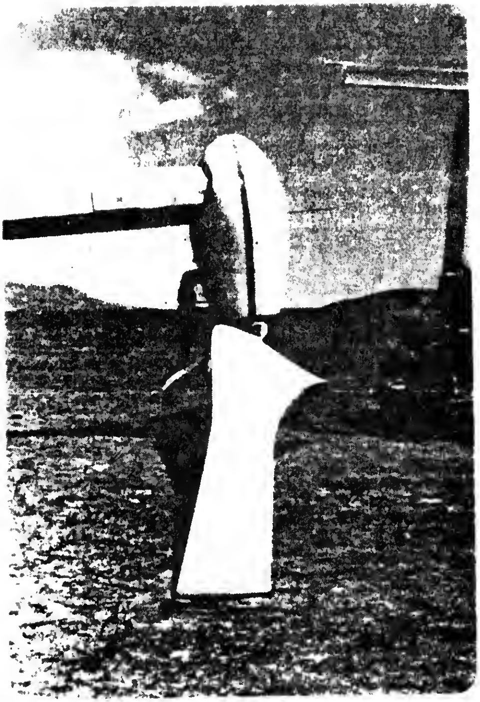


Figure 12.--Erection Sequence #1

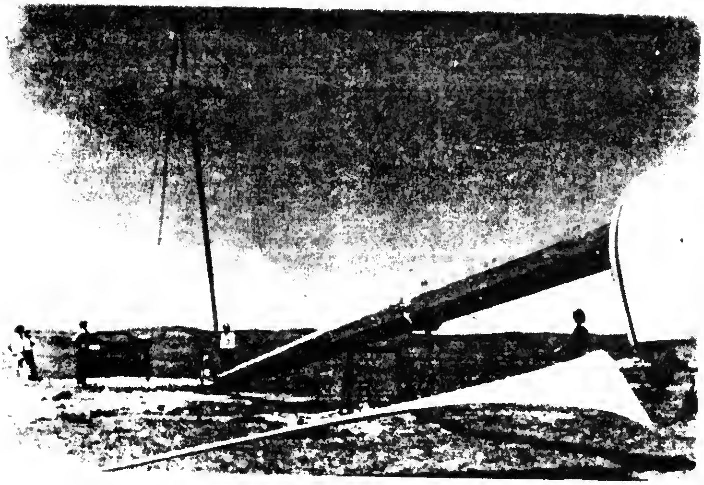


Figure 13.--Erection Sequence #2

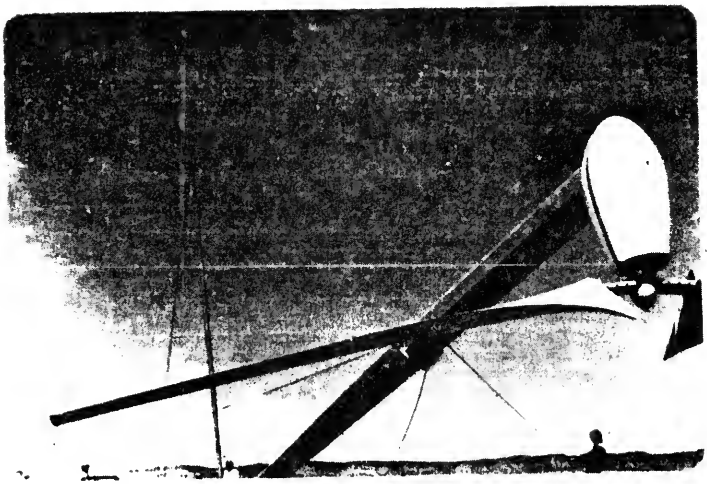


Figure 14.--Erection Sequence #3

Figure 15.--Erection Sequence #4

Figure 16.--Erection Sequence #5

Figure 17.--Erection Sequence #5
Fully Erect

The system was completely installed and operational in less than two days. To insure that the system was operational and wired correctly, electricity was applied to the system from the line, and the generator was operated briefly as a motor.

2.3 System Testing and Modification

This Section on system testing and modification, for purposes of the discussion, is categorized into subsections covering the monitoring systems and the wind energy conversion system.

2.3.1 Wind Monitoring Systems

The three wind monitoring systems discussed earlier are identical to each other in every aspect except their locations. One system is located at each site: Whitehall; Big Timber; and Livingston. Only the testing to insure calibration of each component was given these systems prior to installation. The only modification to the monitoring systems was to rewrite the program for the microprocessors. The method of collecting and printing out the data was changed to the format shown in Appendix C (see separate document). No major physical modifications were made to the monitoring systems following installation.

2.3.2 Wind Energy Conversion System

The wind energy conversion system (WECS) utilized in this project was a Carter Model 25 which is currently available on the commercial market.

The system was tested for three years prior to the described installation. The actual unit installed at Livingston was tested for two weeks by the manufacturer at his plant in Texas.

Installed May 2, 1980 at its present site near Livingston, the WECS experienced many minor problems throughout the term of the project, but other than the six-inch shortening of blades (as described in subsequent paragraphs), no major modifications were made.

The following paragraphs offer a chronological listing of the operating history of the WECS, beginning on the date of May 2, 1980:

During installation and start-up of the WECS on May 2, 1980, Mr. Carter discovered that the brush block that was originally installed in the machine was a special type which should not have been used in this application. Because of the potential for high winds for long periods of time at Livingston, Mr. Carter advised that until the brush block could be replaced, the machine should not be allowed to run unattended for long periods. However, before the brush block could be replaced, the black control box failed. This caused the machine to be shutdown until May 19, 1980 when the brush block and the black box were replaced.

The machine ran for two days, but on May 21, 1980 it was shut down because it was running in the overspeed condition.

In the overspeed condition the WECS operates at excessive speed and the overspeed brake comes on to stop the turbine. After twenty minutes

or so, the overspeed brake automatically resets, and the machine begins to run again. If the problem causing the overspeed continues to exist, then the brake comes on again.

On May 27, 1980 the machine was put through a series of tests to determine the current problem. It was determined that the black box was malfunctioning again. The WECS had operated a total of two days during the month of May, 1980.

On June 2, 1980 the black box was replaced. During the replacement a silicone controlled rectifier (SCR) was damaged and then replaced. The machine then ran for the remainder of the month of June, a total of 28 days.

On July 1, 1980 the WECS was found motoring due to a faulty SCR. The machine was shut down until July 10th when tests were run to determine the problem. On July 15th, Mr. Carter replaced another bad SCR and the yaw damper seal. He also leveled the tower and checked the propeller snubbers. The machine was turned on, and it ran for the remainder of July and part of August, a total of 34 days.

On August 18 the generator was checked and found not working because the out-of-balance brake was on. The brake was reset and the machine restarted. No output of electrical power was recorded between August 18 and August 26. On August 26 the out-of-balance brake was again reset. The WECS ran a total of 22 days during the month of August.

On September 23, the out-of-balance brake was again reset. The brake came on again two days later. On September 25 the tension on the out-of-balance brake spring was increased, and the brake was reset again. The machine ran a total of 26 days during September, 1980.

During the period between May 2, 1980 and September 30, 1980 the WECS produced 8660 kilowatt-hours of electric power for the 96 days of operation; in this five-month period the machine also experienced the lowest average wind speeds of the year.

The WECS operated normally for the first 9 days of October, then no output was recorded. On October 23 Mr. Carter replaced the commutator brushes and springs. He also shortened the propeller tips by six inches so that the propeller could not possibly strike the tower. This was a preventative measure only. On October 24 the machine was found not operating, and Mr. Carter was called again. The machine ran a total of nine days during October.

On November 7, 1980 Mr. Carter adjusted the out-of-balance brake and repaired a broken lead from a transducer pick-up on the gear box. On November 23, 24, 25, and 26, the out-of-balance brake was reset four times. The machine operated a total of 17 days during the month of November.

On December 1, 1980 the out-of-balance brake came on again. The brake was again adjusted and reset. On December 10 the main power breaker was tripped. When the WECS was restarted the generator was found to be operating as a motor. On December 18, Mr. Carter took the generator and

the propeller back to the factory in Texas for repairs. The machine operated a total of eight days during the month of December.

During the 70-day period from October 1, 1980 to December 10, 1980, the average wind speeds had increased as they usually do at this time of year. Over this same period the machine had produced 6020 kilowatt-hours of electrical power in the 35 days of operation.

When the WECS was inspected at the factory in Texas, the wiring in the generator was found to have been overheated. The generator was rewound with new wire of a heavier gauge and a better quality insulation. The out-of-balance mechanism was redesigned from a horizontally-actuated mechanism to a vertically-actuated mechanism. The 100-ampere circuit breaker was replaced by an 80-ampere circuit breaker. The yaw damper was filled with a higher viscosity oil to prevent leakage. The SCR heat sinks were redesigned to prevent burnout of the SCR's.

The Carter WECS was returned to the site at Livingston on January 30, 1981 and installed that same day. The machine operated without further problems to the end of the project. When monitoring was completed on March 11, 1981, the machine had produced a total of 20,960 kilowatt-hours of electric power, since its operational start-up on May 2, 1980; during this period the WECS operated a total of 170 days.

Table 2 shows the operating history of the WECS and the monitoring equipment.

2.4 System Performance

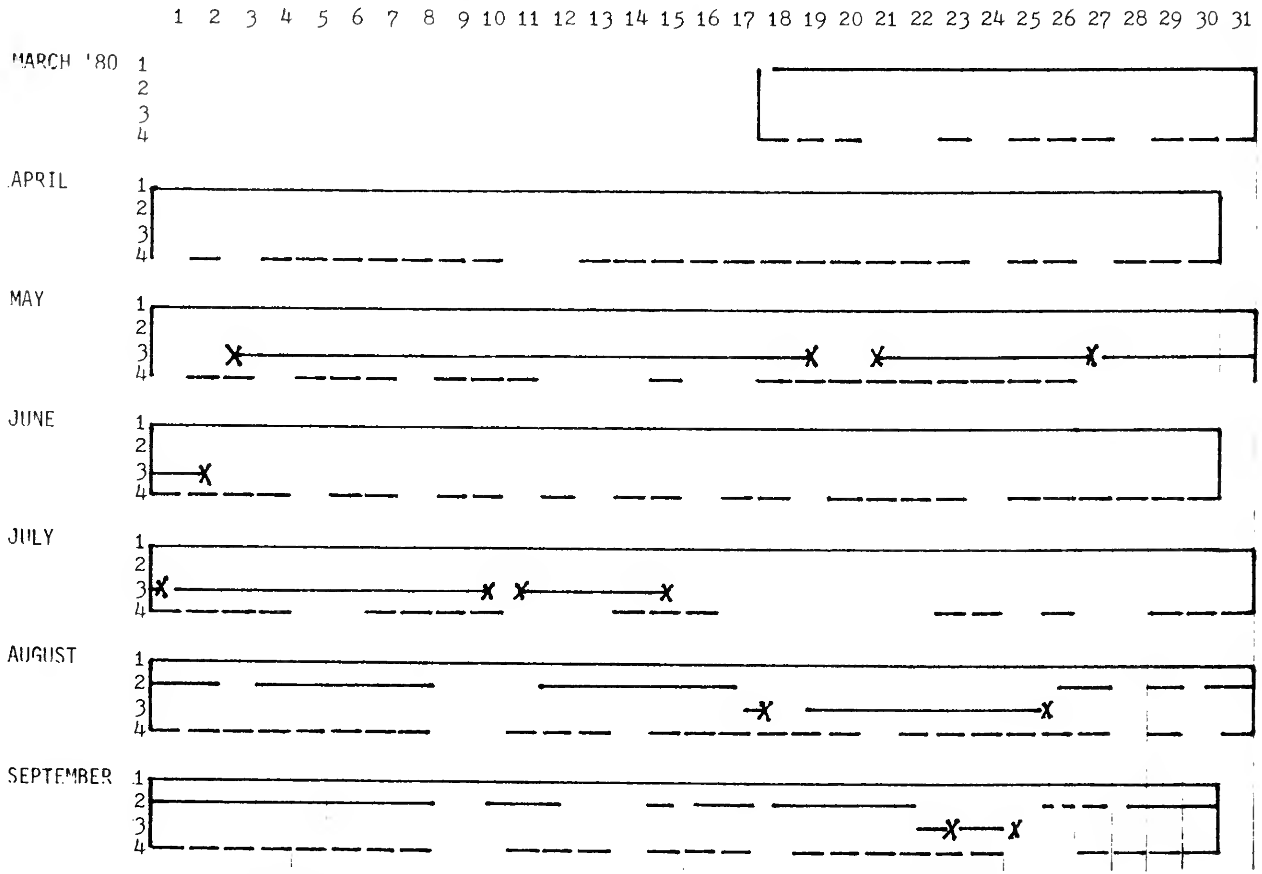
System performance of the wind monitoring equipment was very good. Little data was lost due to equipment failure. During the largest eruption of Mt. St. Helens, May 1980, two days of data were lost because travel to the sites was interrupted and the tapes ran out. During the first month of operation, some data were lost due to a malfunction in the monitoring equipment. After considerable investigation, the problem was discovered in the cassette recorders. During periods when ambient temperatures dropped below 0°F, the speed of the tape recorders slowed enough to compress data onto a very short section of tape making it unreadable by the computer.

The cold weather problem was solved by heating the monitoring instruments. A small insulated box was constructed, just large enough for the microprocessor and the tape recorders. Through heat-loss calculations, it was determined that the instruments could be maintained at 40°F above ambient by applying 3 watts of electric heat. The heat was provided by a 50-ohm power resistor placed in the insulated box with the instruments. The resistor leads were run outside the box and connected to a 12 volt (80 amp/hr) lead-acid battery.

These batteries provided enough energy to warm the instruments for 12 continuous days. During each visit to the sites, the in-place battery at each site was replaced by a fully-charged battery. A total of six lead-acid batteries were used, and each one rotated into service, as required. Also, during each visit to the site, the data tapes were changed. Subsequent to installation of the battery-powered heating system, no further cold-weather problems occurred.

TABLE 2

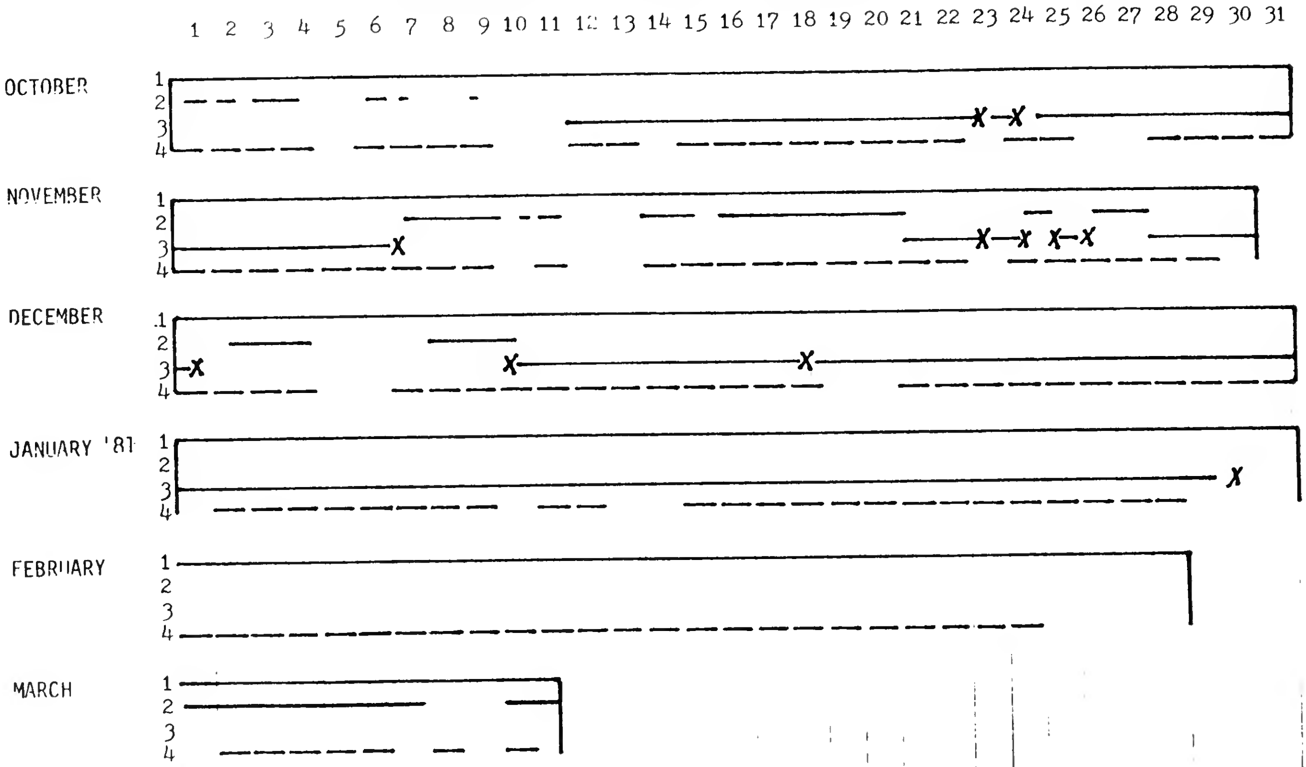
CARTER WECS OPERATING HISTORY (1980-1981)



1. = Wind monitoring in progress.
2. = Turbine output recorded.
3. = Turbine out of order.
4. = Good wind day (10 MPH+).
X. = Turbine malfunction (from MPC Operating History).

TABLE 2 (Continued)

CARTER WECS OPERATING HISTORY (1980-1981)



1. = Wind monitoring in progress.
2. = Turbine output recorded.
3. = Turbine out of order.
4. = Good wind day (10 MPH+).
X. = Turbine malfunction (from MPC Operating History).

During the month of September 1980, both the CR-21 microprocessors at Whitehall and the one at Big Timber malfunctioned. They were removed and sent to Campbell Scientific Co. for repairs. Because of this malfunction, several weeks of data were lost at these two sites. The only other problem experienced with the recording stations was at Big Timber when, on two occasions, an antelope apparently chewed through one of the sensor cables leading into the CR 21.

Complete copies of the data recorded at each station are submitted as Appendix C (separate document). Overall evaluation of the monitoring systems performance, based on use with the project, is excellent.

Table 3 presents a summary of monthly average wind speeds for the three monitoring stations. These data were taken from the daily averages listed in Appendix C (separate document).

When the average wind speeds are known, the power density can be calculated. The power density referred to here is the total power available in the wind passing the site. The power density is normally expressed in watts/meter^2 or:

$$P/A = 1/2 \rho V^3 \qquad (1)$$

where: P/A is power density

ρ is the density of air

V is the wind velocity.

Care must be taken in using the above equation because there are constants and conversion factors which must be employed to make the units correct. Here

<u>TABLE 3</u>

MEASURED MONTHLY AVERAGE WIND SPEEDS

	WHITEHALL (MPH)	BIG TIMBER (MPH)	LIVINGSTON (MPH)
March 1980	12.68	10.97	13.65
April 1980	11.45	9.46	14.65
May 1980	9.66	7.99	12.87
June 1980	9.51	8.92	12.69
July 1980	9.21	8.27	11.69
August 1980	10.12	9.27	13.20
September 1980	10.90	10.28	14.25
October 1980	7.30	11.22	15.35
November 1980	11.47	11.85	20.52
December 1980	14.66	13.94	23.67
January 1981	6.99	8.28	15.68
February 1981	13.53	15.79	21.46

in equation 2, the constants and conversion factors have been applied so that we can use the collected data in its present form.

$$P/A = 0.716\rho V^3 \qquad (2)$$

where: P/A is power density in watts/meter^2

ρ is the density of air in lbm/ft^3

V is the wind velocity in mph.

The density of air (ρ) was adjusted to reflect the average standard density at the Livingston site elevation and the Livingston average ambient temperature. This value for (ρ) is 0.07 lbm/ft^3.

The wind velocities were also corrected in the calculation procedure to reflect the difference in height of the 33-foot monitoring towers and the 55-foot tower required for the Carter wind turbine. The multiplier used in the velocity correction is 1.059. The multiplier was calculated from data taken at three different levels by the Department of Energy's (DOE) tower at the same site.

Using equation 2, the power density at our three sites can be calculated for each month that we have average wind velocities. Table 4 is a summary of the calculated power densities for the velocities given in Table 3.

Figure 18 shows historical data compiled from old airport records. Data are plotted on the same graph with the 1980-81 calculated power density data from Table 4. These plotted data seem to indicate that the year 1980-1981 was

TABLE 4

POWER DENSITY (WATT/M^2) CALCULATED FROM MEASURED AVERAGE WIND SPEEDS*

	WHITEHALL	BIG TIMBER	LIVINGSTON
March 1980	121	79	152
April 1980	89	50	187
May 1980	54	30	127
June 1980	51	42	122
July 1980	46	34	95
August 1980	62	47	137
September 1980	77	65	172
October 1980	23	84	215
November 1980	90	99	514
December 1980	187	161	790
January 1981	20	34	230
February 1981	147	234	588

* Wind speeds were corrected for height using data from Table 3 as the raw data.

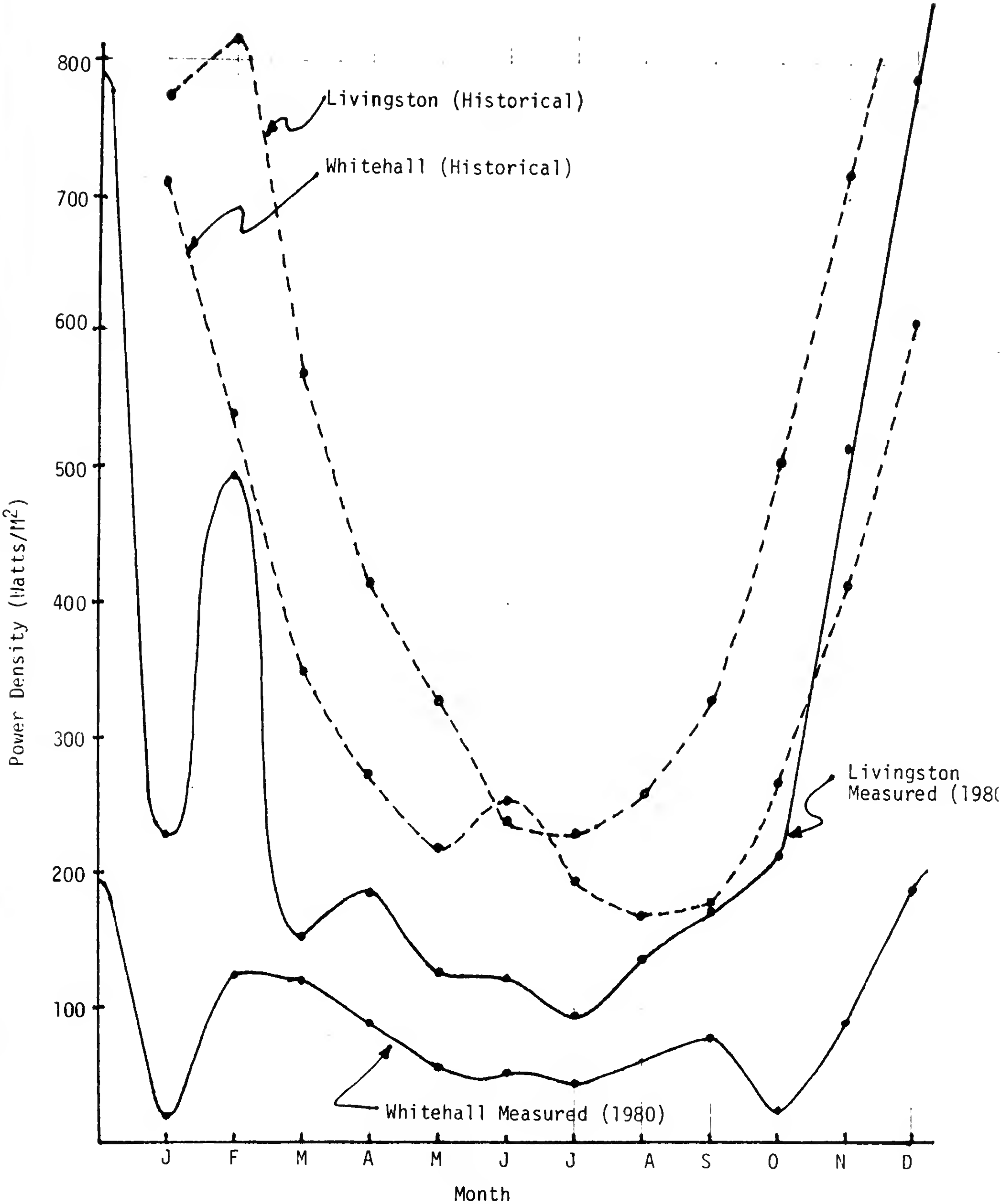


Figure 18.--Power Density by Month for Historical Data and 1930-1981 Measured Data.

a very low wind year at both the Whitehall site and the Livingston site. Such a condition negatively affects the output of a wind energy conversion system.

To visually compare wind speed data from each of the three sites, graphs showing wind speed vs. month of the year were prepared from Table 3. Figures 19, 20, and 21 show the bi-weekly average wind speeds measured for Whitehall, Big Timber, and Livingston, respectively. For comparison, Figure 22 shows monthly average wind speeds for each of the sites. The dashed horizontal line, drawn at the 8-mile-per-hour level on each of these graphs, represents the starting speed of both the Carter wind turbine and most of the wind turbines on the commercial market.

To accurately predict the electric power that could be produced at each of the three sites, it was necessary to know the percentage of time that the wind blows at different speeds at each site. Power predictions were based on actual measured wind speeds (shown in Table 3) and not on the historical data presented earlier.

The development of wind speed frequency distribution data needed for accurate power predictions required the writing of an additional computer program to search the collected wind speed data stored in the computer. These frequency distribution data are presented in Table 5 and are also graphically illustrated in Figures 23, 24, and 25 for Whitehall, Big Timber, and Livingston, respectively. The wind speed frequency distribution data were also plotted on a monthly basis for each site and these graphs are in Appendix B.

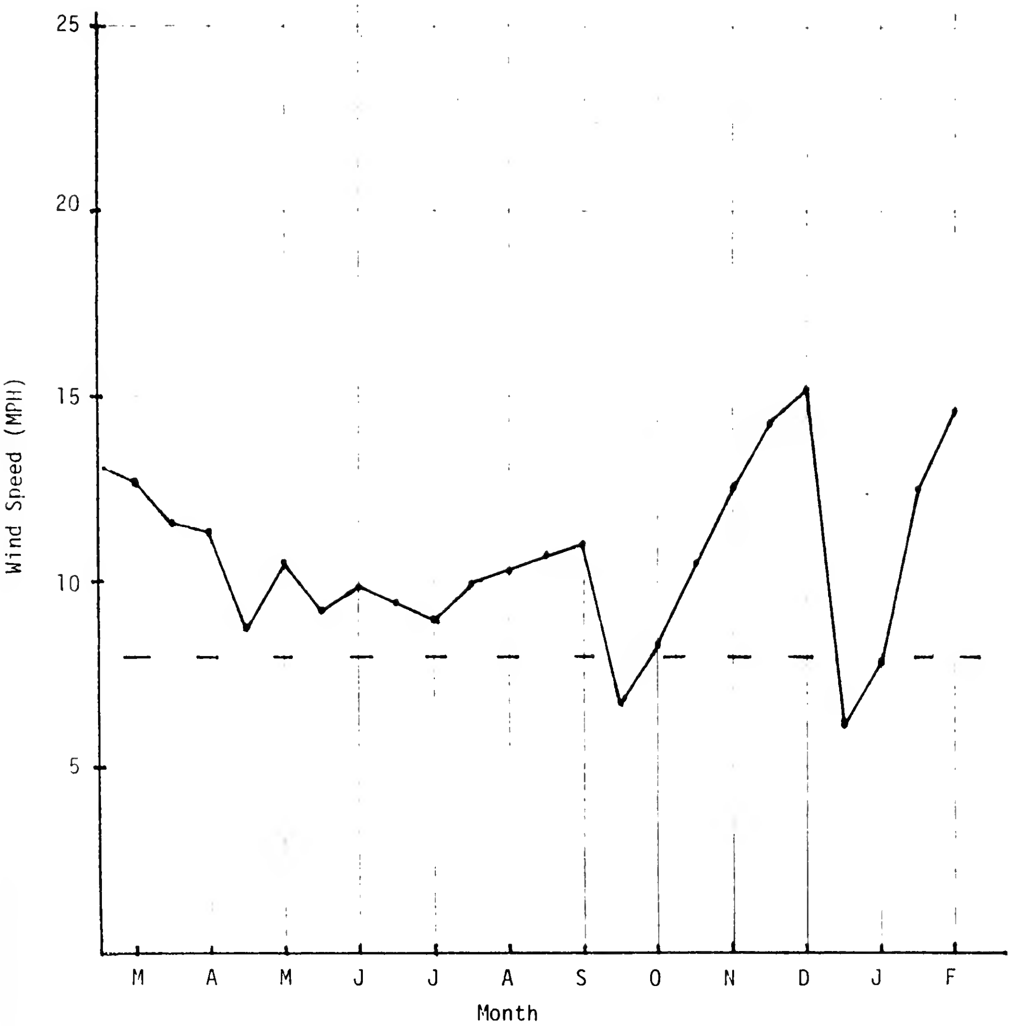


Figure 19.--Bi-Weekly Average Wind Speeds for Whitehall Site 1980 - 81.

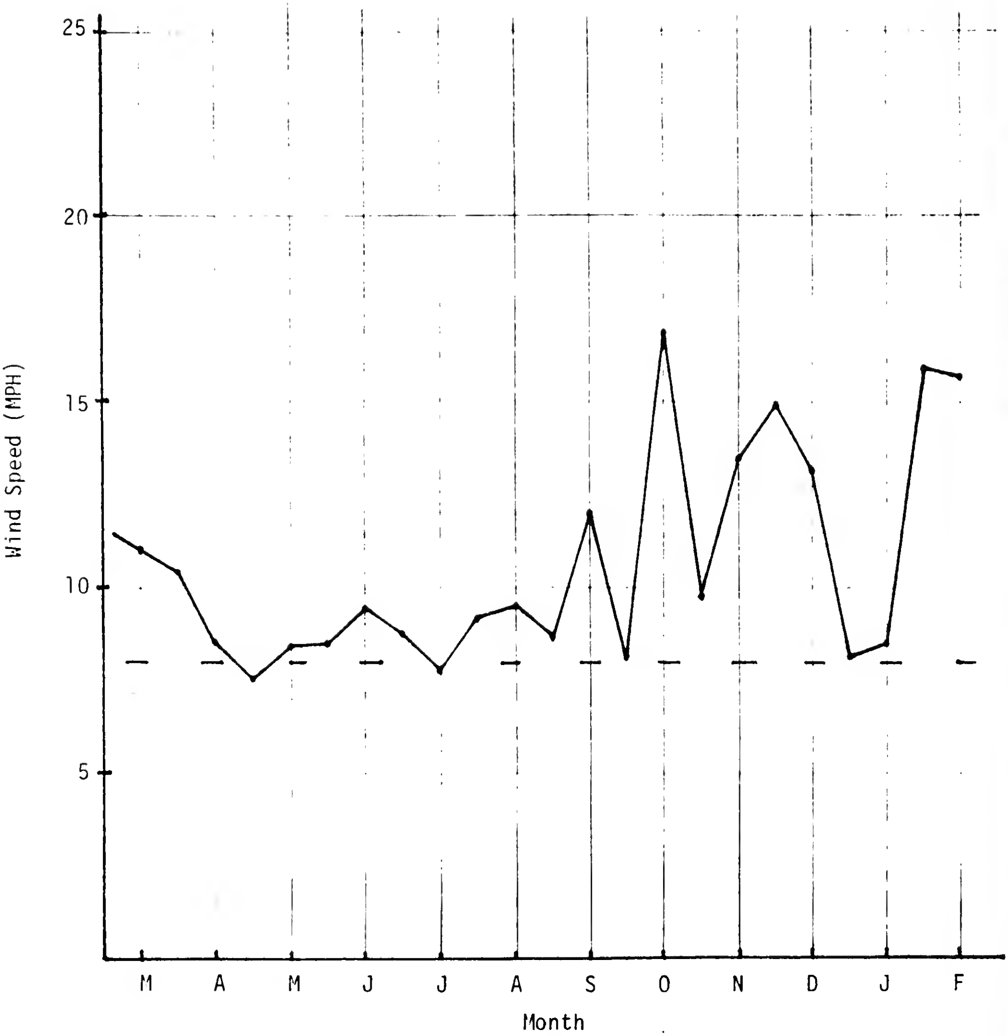


Figure 20.--Bi-Weekly Average Wind Speeds for Big Timber Site 1980-81.

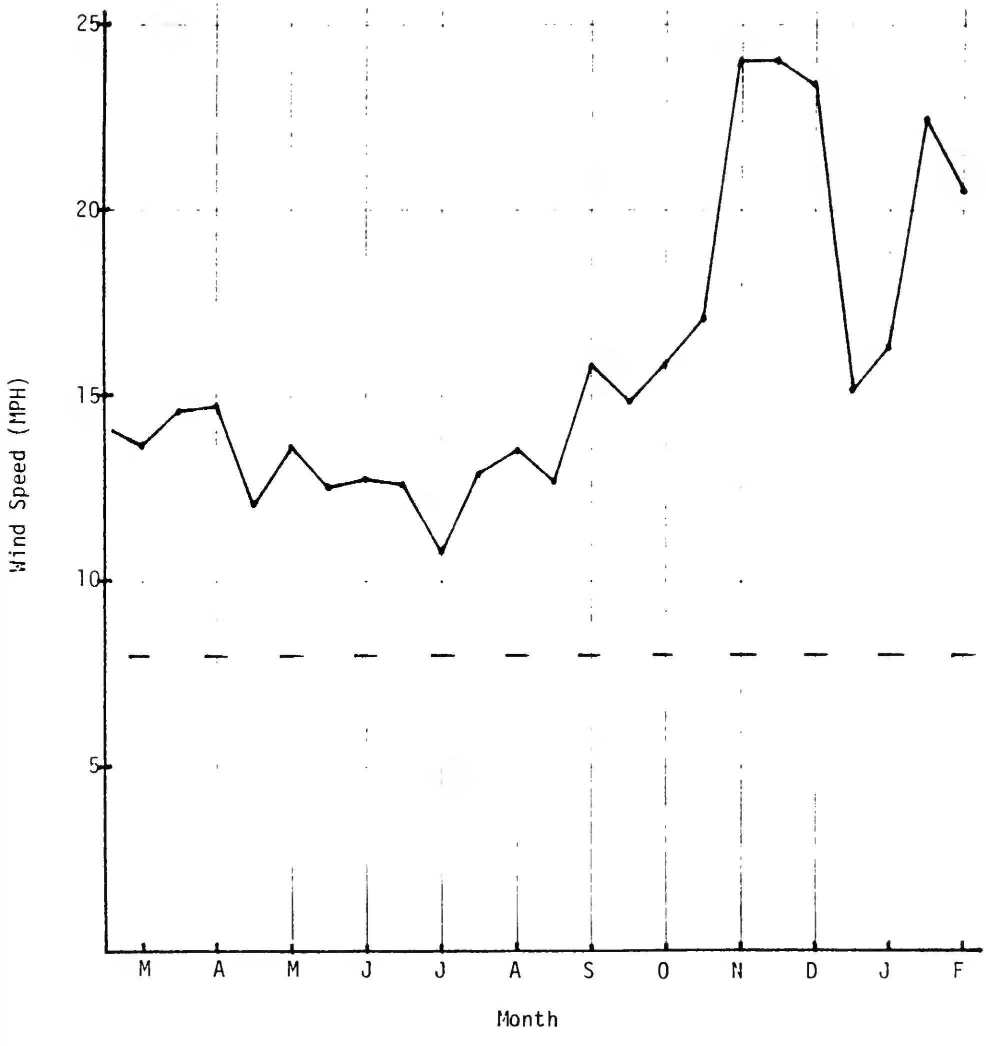


Figure 21.--Bi-Weekly Average Wind Speeds for Livingston Site 1980-81.

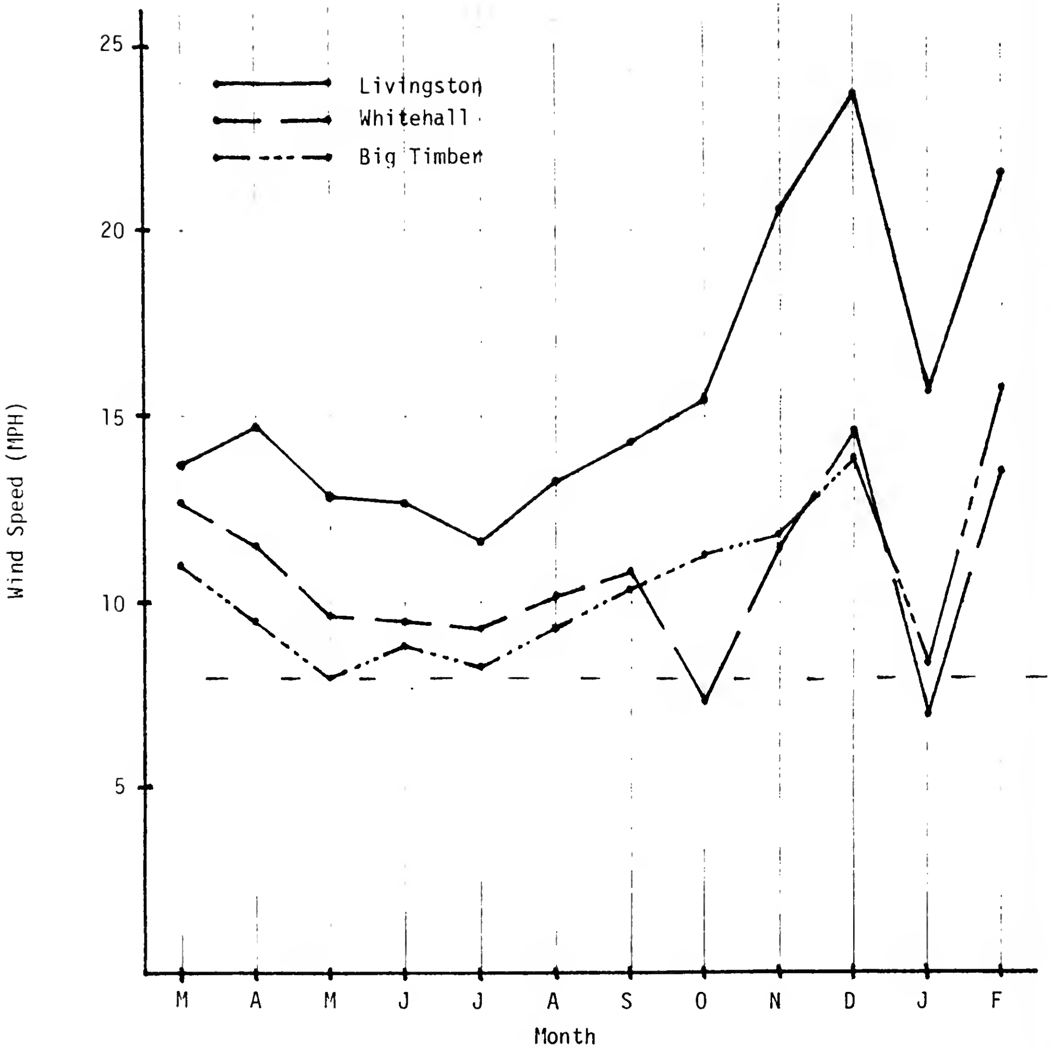


Figure 22.--Monthly Average Wind Speeds for Livingston, Whitehall, and Big Timber.

<u>TABLE 5</u>

YEARLY WIND SPEED FREQUENCY DISTRIBUTION DATA FOR THREE SITES

WIND SPEED RANGE (MPH)	WHITEHALL (% of year)	BIG TIMBER (% of year)	LIVINGSTON (% of year)
0-3	8.1	11.5	5.2
3-6	27.0	26.7	14.2
6-9	19.1	17.0	11.6
9-12	12.3	11.6	10.5
12-15	9.3	8.4	10.8
15-18	7.2	6.5	11.0
18-21	5.6	5.3	9.9
21-24	4.4	4.3	7.9
24-27	3.1	3.3	5.8
27-30	1.9	2.2	4.0
30-33	1.1	1.5	2.7
33-36	0.5	0.8	2.0
36-39	0.2	0.5	1.4
39-42	0.1	0.3	1.1
42-45	0.1	0.1	0.8
45-48	0.05	0.1	0.6
48-51	0.03	0.05	0.4
51-54	----	0.03	0.2
54-57	----	----	0.1
57-60	----	----	0.1

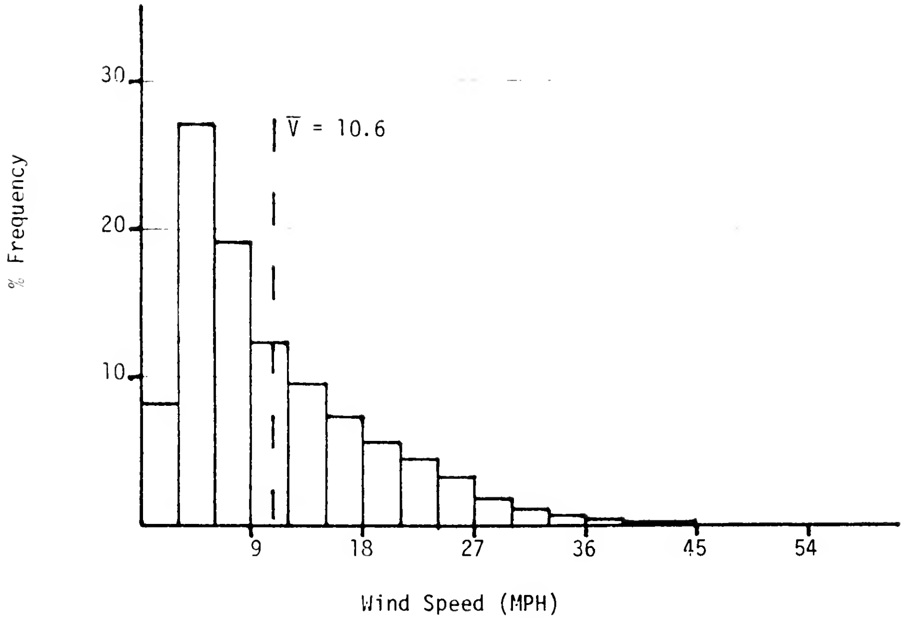


Figure 23.--Wind Speed Frequency Distribution for Whitehall from March 1980 through March 1981.

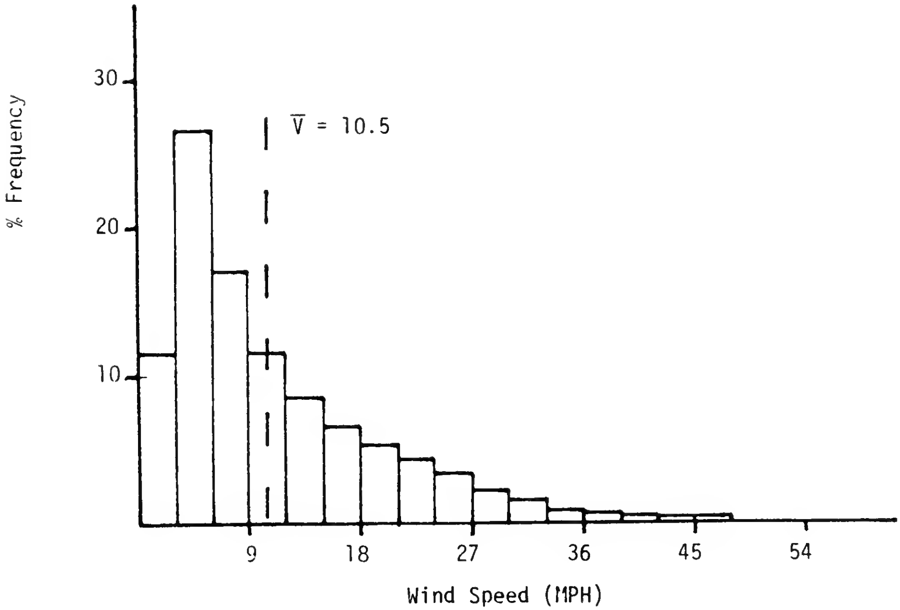


Figure 24.--Wind Speed Frequency Distribution for Big Timber from March 1980 through March 1981.

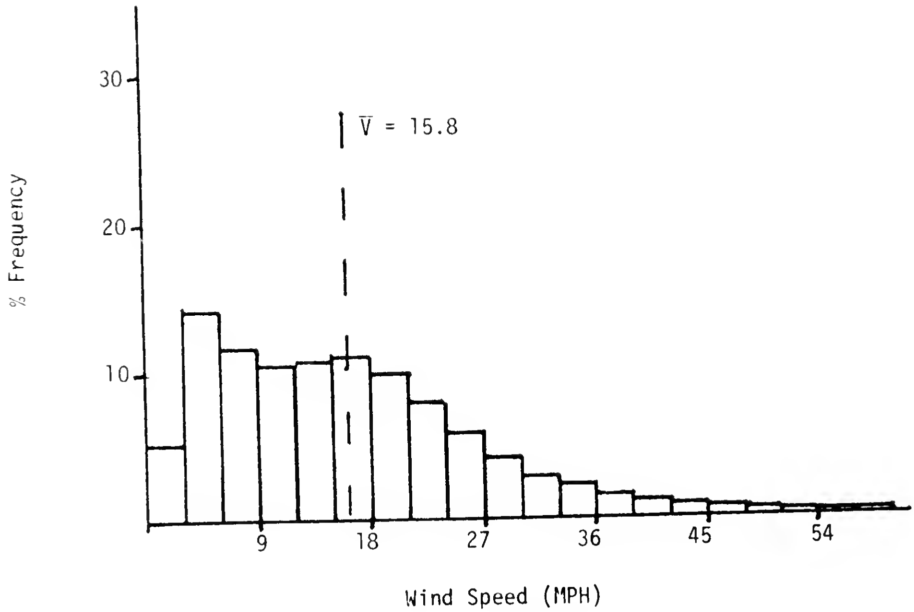


Figure 25.--Wind Speed Frequency Distribution for Livingston from March 1980 through March 1981.

To arrive at an accurate prediction of the power that could be produced, the next step was to search all of the data relating to power actually produced by the Carter wind turbine at Livingston. These data, supplied by Montana Power Company, were searched and compared with the monitored wind data. These two sets of data could only be compared for specific times when the wind turbine was known to have been operating. Both sets of data were accumulated along with the date and time of day. This allowed an accurate comparison of the two data sets. The power produced at various wind speeds by the Carter Wind Turbine at the Livingston site is shown in kilowatts per hour, in graphical form, in Figure 26. However, this power output was measured at the Livingston site where the elevation is 4660 feet above sea level. The power output could be as much as 10% higher at elevations near sea level because of increased density of the air at lower elevations. Figure 26 can be used to determine the power output that can be expected from the Carter wind turbine.

It is possible to make calculations of wind energy conversion system efficiency based on the power generated data and the wind speed data. These two sets of data were used to calculate the power coefficient for the Carter machine. The power coefficient (Cp) is defined as:

$$Cp = \text{Power Generated/Total Power Available}$$

It must be remembered that the accepted theoretical limit (Betz Limit) on wind energy conversion system efficiency is 59.3%. This means that 59.3% is the maximum percent of power that can be extracted from the total power in the wind.

The above equation for the power coefficient was used to plot the WECS efficiency shown graphically in Figure 27. Figure 27 shows that the maximum

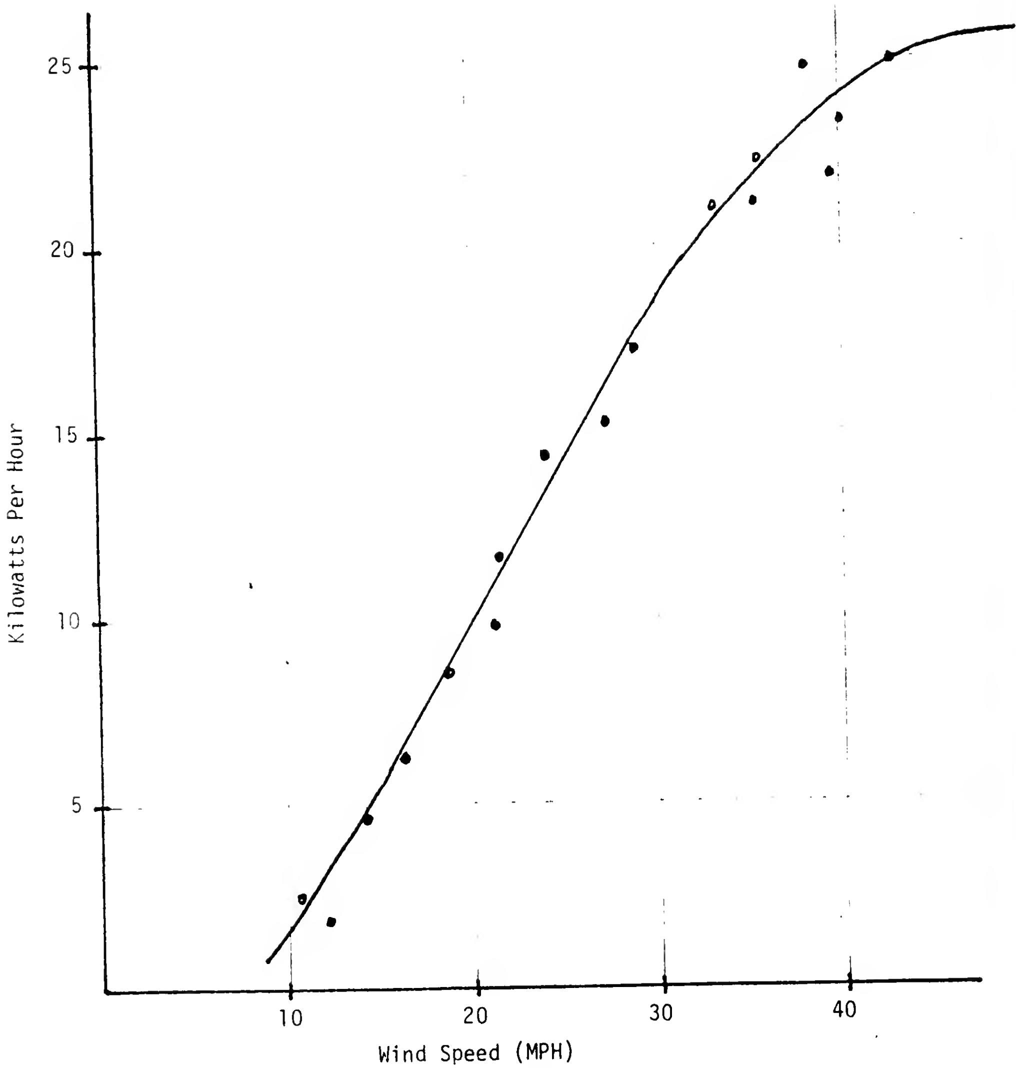


FIGURE 26.--Measured Power Output of Carter Wind Turbine At Livingston Site (Elevation 4660 FT. Above Sea Level)

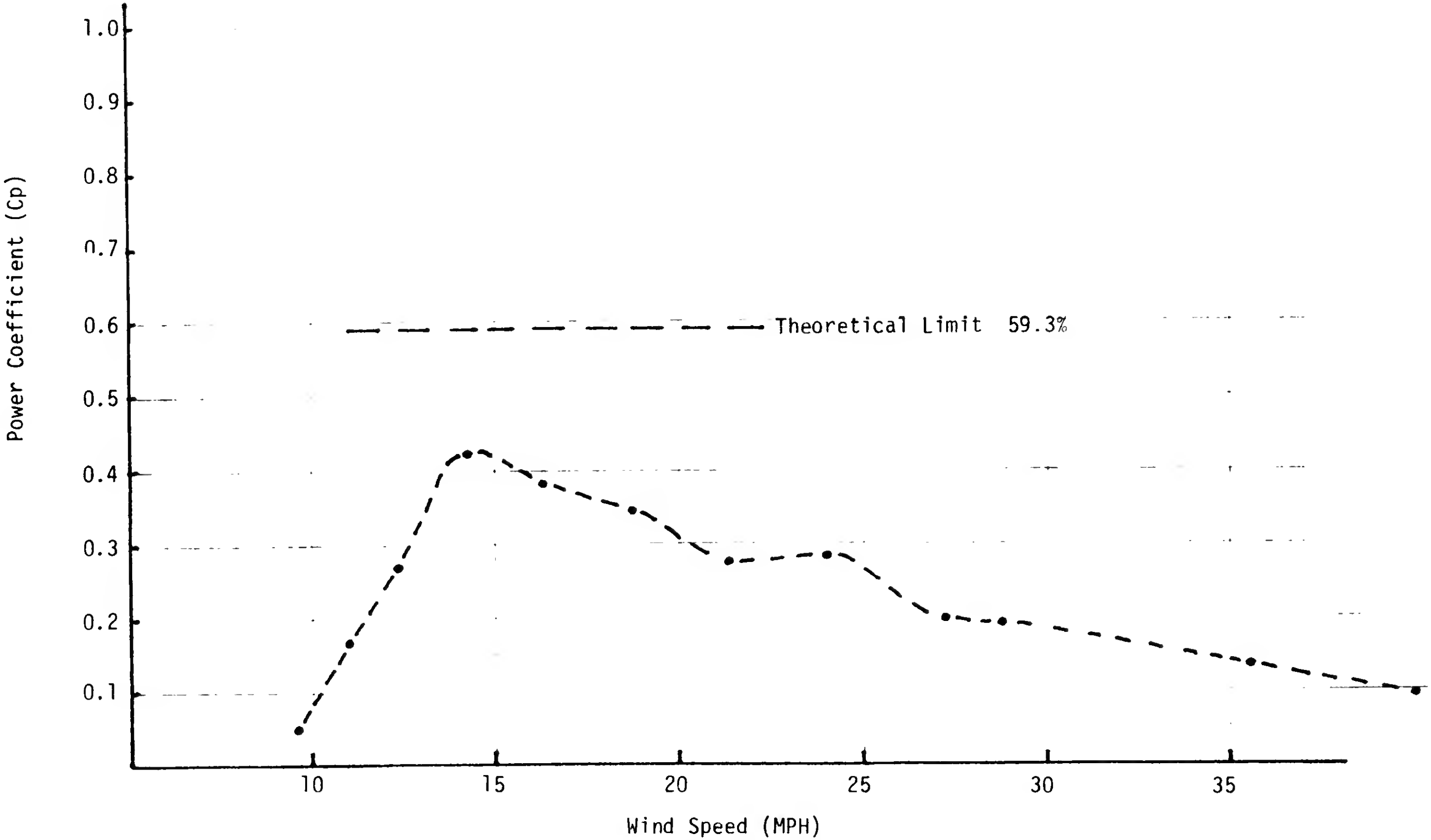


Figure 27. Power Coefficient Vs. Wind Speed for Efficiency of Carter WECS at Livingston Site.

efficiency obtained by the Carter WECS at the Livingston site was 42% at a wind speed of 14.2 mph. This efficiency curve was compared with published efficiency curves of many other wind energy conversion systems and was found to be one of the highest in the industry. As can be seen from Figure 27, the WECS does not produce this efficiency at all wind speeds. However, it is most efficient very close to the measured average wind speed of 15.8 mph which occurs at the Livingston site.

Using calculations based on 1) the efficiency curve of Figure 27; 2) the power-output curve in Figure 26; and 3) the power-density equation, a chart can be constructed that will enable the power output to be predicted at any site. The results shown in Table 6 are that calculation for the Carter wind turbine at the Livingston site. Figure 28, a graphical representation of the calculated data contained in Table 6, shows the estimated monthly power output of the Carter wind turbine at various wind speeds.

Two separate methods of predicting the yearly power output will be discussed in subsequent paragraphs. The first method uses the average wind speed to determine the yearly power output. The second method uses the wind speed frequency distribution to predict the yearly power output. The two methods of predicting the power output are discussed here because they are both valid methods; however, the second method using the wind speed frequency distribution matched the actual power output very closely.

Using the first method, the average yearly wind speed from Table 7 can be used to determine the monthly power output from Figure 28 and then multiply that number by twelve. The yearly average wind speed at the Livingston site

TABLE 6

ESTIMATED POWER OUTPUT OF CARTER WIND TURBINE AT VARIOUS WIND SPEEDS
(DATA TAKEN AT LIVINGSTON SITE)

WIND SPEED RANGE (MPH)	MID-POINT (MPH)	POWER DENSITY (WATTS/M^2)	TOTAL POWER AVAILABLE IN CARTER SWEEP KILOWATT/HRS	% EFFICIENCY AT THIS WIND SPEED	ESTIMATED KILOWATT/HRS CARTER TURBINE	ESTIMATED KILOWATT-HRS PER MONTH
0-3	--	--	--	--	--	--
3-6	--	--	--	--	--	--
6-9	--	--	--	--	--	--
9-12	10.5	58	4.33	12.5	0.5	360
12-15	13.5	123	9.18	40.0	3.7	2660
15-18	16.5	225	16.8	38.0	6.4	4610
18-21	19.5	372	27.8	33.0	9.2	6620
21-24	22.5	571	42.6	28.0	11.9	8570
24-27	25.5	831	62.0	25.0	15.5	11160
27-30	28.5	1160	86.6	19.0	16.5	11880
30-33	31.5	1567	117.0	17.5	20.5	14760
33-36	34.5	2058	153.6	14.5	22.3	16060
36-39	37.5	2643	197.0	12.5	24.6	17710
39-42	40.5	3329	248.0	10.0	24.8	17860

TABLE 6 (Continued)

ESTIMATED POWER OUTPUT OF CARTER WIND TURBINE AT VARIOUS WIND SPEEDS
(DATA TAKEN AT LIVINGSTON SITE)

WIND SPEED RANGE (MPH)	MID-POINT (MPH)	POWER DENSITY WATTS/M^2	TOTAL POWER AVAILABLE IN CARTER SWEEP KILOWATT/HRS	% EFFICIENCY AT THIS WIND SPEED	ESTIMATED KILOWATT/HRS CARTER TURBINE	ESTIMATED KILOWATT-HRS PER MONTH
42-45	43.5	4126	308.0	8.1	25.0	18000
45-48	46.5	5039	376.0	6.7	25.0	18000
48-51	49.5	6079	454.0	5.5	25.0	18000
51-54	52.5	7253	541.0	4.7	25.0	18000
54-57	55.5	8568	639.0	4.0	25.0	18000
57-60	58.5	10034	749.0	3.3	25.0	18000

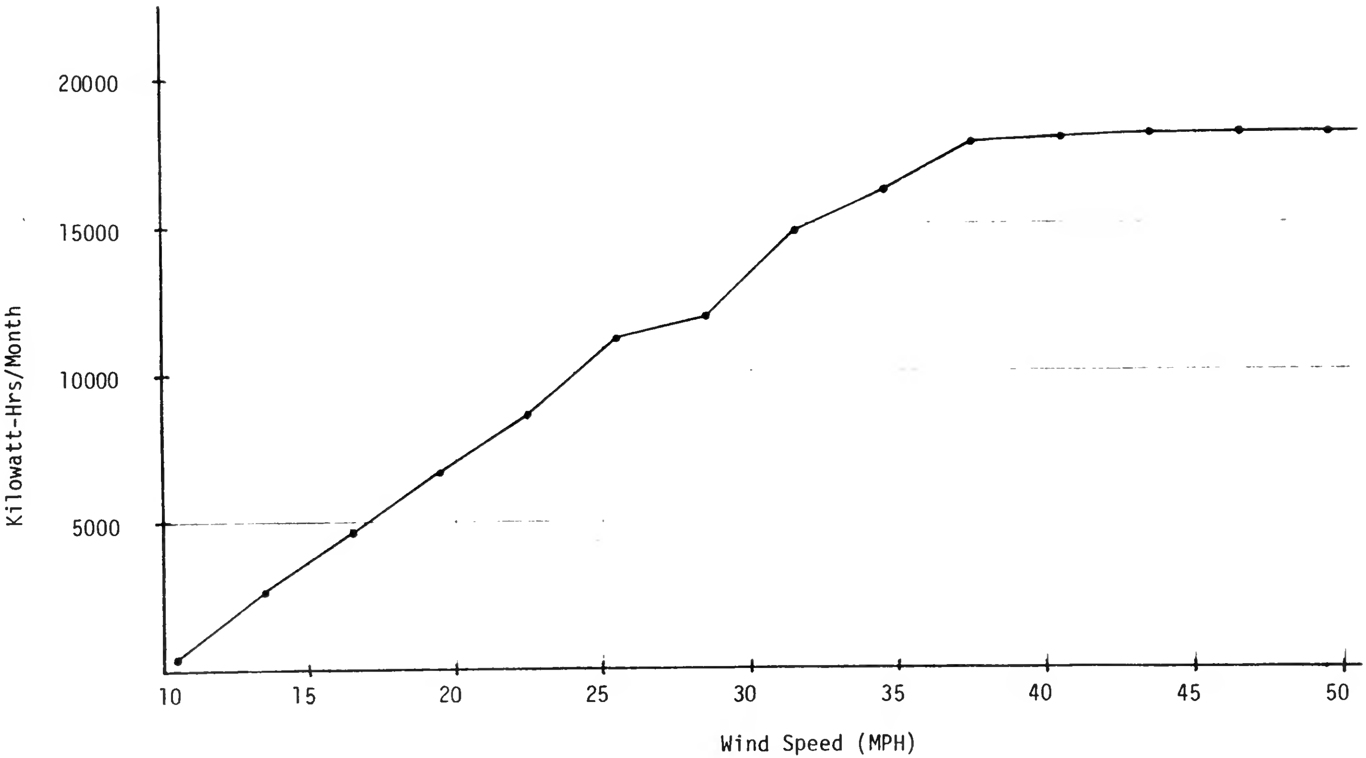


Figure 28.--Estimated Power Output for One Month of Carter Wind Turbine at Various Wind Speeds

TABLE 7

ESTIMATED YEARLY POWER OUTPUT FOR EACH SITE, CALCULATED FROM MEASURED WIND SPEED FREQUENCY DISTRIBUTION DATA

	AVERAGE WIND SPEED (MPH)	ESTIMATED YEARLY ELECTRIC OUTPUT (kW-hr)
WHITEHALL	10.62	27,640
BIG TIMBER	10.52	29,900
LIVINGSTON	15.81	59,000

(Table 7) is about 16 mph and the power output curve of Figure 28 shows approximately 4400 kWhr per month. Multiply the 4400 kWhr per month times 12 months per year and our yearly estimate of power generated at the Livingston site would be 52,800 kWhr per year. This calculation can be misleading for a yearly power output, and the frequency distribution method is recommended.

Using the second method, the yearly output estimate can also be predicted by taking the percentage of time the wind blows in the specific wind speed ranges from the frequency distribution data for Livingston on Table 5 and multiplying that percentage time 8760 hours per year and then multiplying that times the estimated kilowatts/hour for the Carter turbine in column 6 of Table 6. A sample calculation for a Livingston wind speed range of 9 to 12 mph would be 10.5% from Table 5 multiplied by 8760 multiplied by 0.5 kWhr from Column 6 of Table 6 resulting in a calculation of 459.9 kWhr for the wind speed range of 9 to 12 mph. This calculation must be performed for each speed range listed on Table 5, and then totalled for the total yearly output. This estimated yearly output calculation should be more accurate than the first method, using the average wind speed for the site, because two sites with identical average wind speeds can have widely varying wind speed frequency distributions.

This frequency distribution method of calculation was performed for each of the three sites, and the results of those calculations are contained in Table 7. By examining Table 7, it is evident that Big Timber had a slightly lower average wind speed than did Whitehall; however, the estimated yearly power output is higher at Big Timber. This is due to the difference in the wind speed frequency distribution at the two sites.

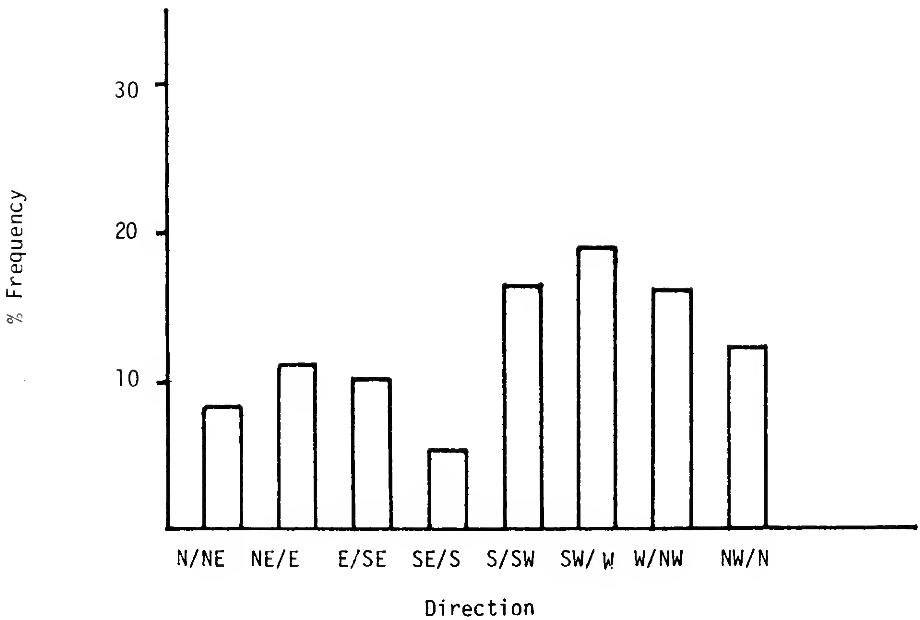


Figure 29.--Wind Direction Frequency Distribution for Whitehall, Montana

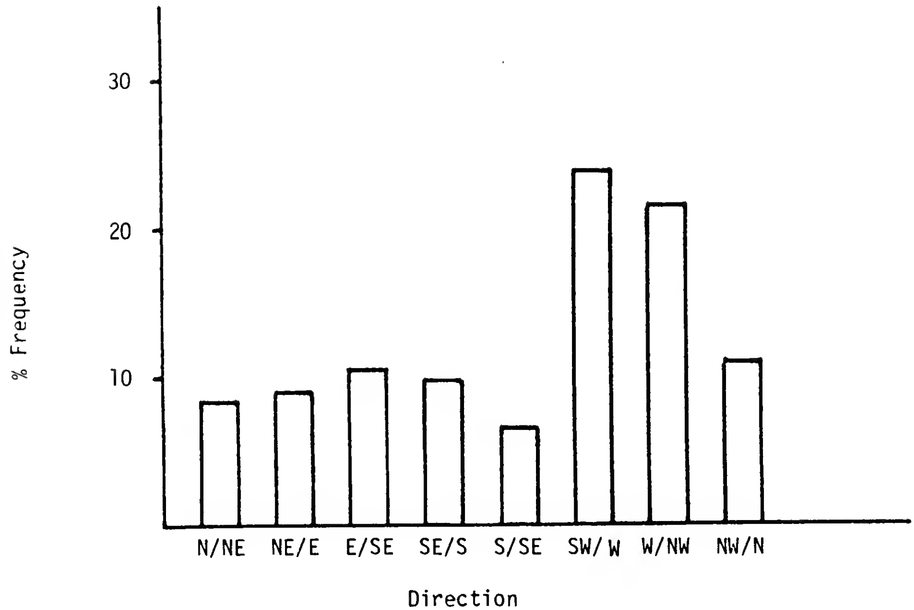


Figure 30.-- Wind Direction Frequency Distribution for
Big Timber, Montana

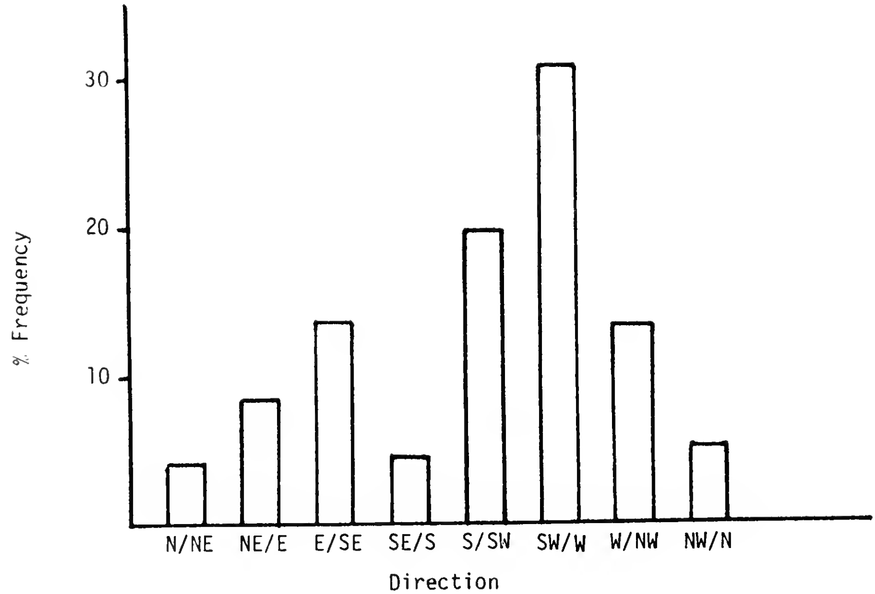


Figure 31.--Wind Direction Frequency Distribution for Livingston, Montana

Another factor pertinent to wind energy conversion system siting is the prevailing wind direction at the proposed site. The wind direction was also monitored at Whitehall, Big Timber, and Livingston. This wind direction data was also run through the frequency distribution program and the results are shown in Figures 29, 30, and 31.

2.5 Economic Evaluation

This Section will present a discussion of economic payback periods for the Carter wind energy conversion system, based upon system costs divided by annual energy savings. These calculations are quite simple, but several variables must be considered.

The first variable depends on whether the average wind speed method or the frequency distribution method is used to estimate the yearly power output for the WECS at a given site. For example, at the Livingston site, the estimated yearly power output using the average wind speed method is 52,800 kWhr per year. Use of the frequency distribution method shows 59,000 kwhr per year. For the three sites in question, the frequency distribution method will be used because it has been shown to be more accurate. However, these calculations will not be transferable to other sites that have not been extensively monitored for the wind speed frequency distribution.

The other major variable is the price per kilowatt-hour that the power company will pay for the generated electricity in the area where the WECS is installed. At the time of this writing, the Montana Public Service Commission has not ruled on what this price will be. Therefore, in order to discuss this

TABLE 8

PAYBACK PERIODS FOR CARTER MODEL 25 WECS AT LIVINGSTON, MONTANA

0.02 $/KW-HR	0.03 $/KW-HR	0.04 $/KW-HR	0.05 $/KW-HR	0.06 $/KW-HR	0.07 $/KW-HR
19.5 YR	13.0 YR	9.7 YR	7.8 YR	6.5 YR	5.6 YR

TABLE 9

PAYBACK PERIODS FOR CARTER MODEL 25 WECS AT WHITEHALL, MONTANA

0.02 $/KW-HR	0.03 $/KW-HR	0.04 $/KW-HR	0.05 $/KW-HR	0.06 $/KW-HR	0.07 $/KW-HR
41.6 YR	27.7 YR	20.8 YR	16.6 YR	13.9 YR	11.9 YR

TABLE 10

PAYBACK PERIODS FOR CARTER MODEL 25 WECS AT BIG TIMBER, MONTANA

0.02 $/KW-HR	0.03 $/KW-HR	0.04 $/KW-HR	0.05 $/KW-HR	0.06 $/KW-HR	0.07 $/KW-HR
38.5 YR	25.6 YR	19.2 YR	15.4 YR	12.8 YR	11.0 YR

payback period, a range of purchase rates needs to be considered in conjunction with the estimated power output at each of the three sites.

Tables 8, 9, and 10 present the payback periods in years, considering these variables. These tables were developed based on the assumptions discussed and should not be used for other wind energy conversion systems or other sites.

A sample calculation which was used to develop these tables follows:

$$\text{Payback period} = \frac{\text{System Purchase Price}}{\text{Estimated Output (kW-hr)} \times \text{Purchase Rate}}$$

$$\text{Payback period} = \frac{\$23,000}{59,000 \text{ kW-hr} \times .04} = 9.7 \text{ years}$$

When analyzing the data in Tables 8, 9, and 10, it must be kept in mind that the purchase rate has not been established by the Montana Public Service Commission. If the purchase rate is 4 cents per kW-hr, the payback period looks fairly good. However, if the purchase rate is 2 cents per kW-hr the payback period will double. This payback period will decrease as time goes by due to the escalating costs of electricity. Another important factor to keep in mind is the total system cost. For this particular system, as installed at Livingston; the cost was $25,600. However, the price at the time of this writing is about $23,000. The $23,000 figure was used for these calculations.

As discussed earlier, the wind speeds measured during this project were substantially lower than those shown by the historical data. If the historical data is a true indication of the wind speeds for an average year, the payback period would decrease substantially if the higher wind speeds are used to calculate the yearly power output.

3.0 CONCLUSIONS AND RECOMMENDATIONS

This Montana wind energy R&D program is significant in many aspects. It is the first wind energy conversion system in Montana to be tied directly into the utility grid. It is the largest wind energy conversion system operating in Montana to date. It is the first wind project to correlate between different sites and determine usefulness of wind-generated electricity. It is the first wind project in Montana with the capability to accurately calculate the cost of electricity generated and determine payback periods for the system. Also, the project is significant in that it is a joint effort between state government (DNRC), a utility (MPC), and private business (MERDI) to demonstrate the value of a renewable energy source.

Another significant spin-off from this project is the potential for future wind-related projects in Montana. Last year MERDI and MPC wrote a proposal to the Department of Energy (DOE) for installation of a Boeing MOD-2 wind energy conversion system and to have Livingston selected as a future candidate site for large wind energy conversion systems. Livingston did not get chosen for a MOD-2, but did get selected as one of 17 wind monitoring sites in the United States for future large WECS. Another spin-off of program work in the Livingston area was the proposal that MERDI and the City of Livingston prepared for a wind-powered Sewage Treatment Plant at Livingston. This proposal was considered for funding by the Environmental Protection Agency (EPA) and the Montana Department of Health and Environmental Sciences; the EPA expressed much interest in the project.

The monitoring systems, as discussed earlier, and the wind energy conversion system as installed are all feasible for many uses. Both the technical and operating feasibility have been demonstrated by this program. In good wind sites, i.e., greater than 12 mph average wind speed, the Carter Model 25 could have any number of technical and economical applications. It is possible to use these systems tied into utility grid systems or for isolated load-type systems. They may be used with or without storage systems and can be supplied with either single-phase or three-phase generators.

Once permission was granted on November 27, 1979 to purchase and install a wind energy conversion system, the program was conducted as proposed to DNRC and encountered no major problems. The only problem area of the entire project was that the wind energy conversion system experienced many breakdowns during the first seven months of operation which could be expected of a first-of-the-run production model. The WECS operated perfectly after January 30, 1981, the date on which it was reinstalled. The problem with breakdowns was judged as being due to no one agency, and DNRC saw fit to extend the program until March 11, 1981 to obtain the necessary performance data.

It is apparent that further development should be conducted for the purpose of demonstrating wind farms or arrays of wind energy conversion systems. These farms could be either larger or smaller machines than the Carter Model 25 or, in fact, could be the Carter Model 25. They should definitely be tied into a utility distribution system so that output of the array could be adequately used. Also, more work needs to be conducted on identification of sites that have moderate or higher mean average wind speeds. Plans could then be developed for determining the best use of those particular wind sites.

Generally, the systems utilized in the program performed well. All three of the monitoring systems performed even better than expected and little data was lost due to equipment failure. The Carter Model 25 experienced some "run-in" problems initially, but throughout the balance of the program seemed to be performing quite well.

4.0 MONITORING

The contract funding period has expired; thus continued monitoring of the WECS by project personnel will not be possible. It is likely that the monitoring towers and equipment will be taken down and moved to other sites for use on new projects. MPC has received ownership of the wind energy conversion system and whether the system will continue to provide performance data is unknown at this time.

5.0 PUBLIC AVAILABILITY

Because MPC owns the wind energy conversion system and has an option on the land around the site, any arrangements for site visits should be made through MPC. Mr. Leonard Decco, Senior Engineer, is the person to contact at MPC in this regard. The wind energy conversion system is only 100 yards off the road and can be observed very well from the road; thus it may be visited and viewed from the county road at anyone's convenience. Many people visited the site to date and apparently were well satisfied with the visits.

It would be impossible to estimate the number of persons that have visited the wind energy conversion system site. During the two days of installation and start-up, over 100 people were there and many more drove by to look from the county road. Their general response was one of appreciation and interest and they wanted to know as much as possible about the system.

Park County Commissioner, Ken Spaulding, has stated that the County might put a traffic counter on the road to get an idea of the extent to which visits to the site increased traffic on the road; he can be contacted in regard to this matter. If such data become available, they could give a rough idea of how many people have visited the site.

Distances traveled by people to see the system included trips from as far away as Billings, Helena, and Butte during the first two days and it is probably true that people traveled 100 to 170 miles specifically to see the system.

6.0 PROGRAM EVALUATION

One problem area is seen to exist with the wind energy assessment programs being funded by DNRC. Many people are being funded to assess wind potential around the state. Each of these projects uses different equipment to monitor the wind, different methods of predicting the power available, and different formats for showing results. Thus, it is very difficult at the present time to compare these wind sites to each other. Most of these projects are monitoring average wind speeds only. Calculations done only from average wind speeds are not accurate enough to adequately predict the power output potential of a site.

The wind energy program has provided the basic data base and installation capability to evaluate and monitor the potential for existing and future wind energy sites in the State of Montana. This background of experience should enhance future wind energy conversion system installations throughout the state and support an increased application of wind renewable energy.

The successful completion of this program, and distribution of the report to the citizens of the state should enrich and expand the wind energy plans and interests of DNRC. This program should assist with the technical effectiveness and the economic aspects of wind energy installations and create an interest in wind energy throughout the State of Montana.

Finally, this program and the report offer a limited-scope example of successful wind energy production which can serve as a model for future larger-scale installations in Montana.

APPENDIX A

MONITORING EQUIPMENT

CAMPBELL CR-21 MICROLOGGER

The Campbell C-21 Micrologger is a miniature, battery operated, computing data recorder that can handle up to seven analog inputs and two pulse counting inputs. User programmable signal conditioning in the CR-21 can measure volts, millivolts, AC and DC resistance, pulse counts, and counting switch closures. With this signal conditioning capability, the CR-21 is well suited to monitor signals from a wide variety of transducers, recording such parameters as temperature, humidity, solar radiation, wind speed, wind direction, pressure, precipitation, event occurrences and many others.

The CR-21 is a battery-powered microcomputer with a real-time clock, a serial data interface, and a programmable analog-to-digital converter. Once each minute, the micrologger samples the input signals according to input programs specified in a user-entered input table, then processes that data, and stores it according to output programs specified in a user-entered output table. Input programs specify the type of signal conditioning and A/D conversion to be done, including linearization of selected input signals. Output programs further process the sensor outputs to obtain averages, maximums, minimums, totals, histograms, wind run, wind rose, time of event, and standard deviation.

PROGRAM CR-21

KEY IN	DISPLAY
SWITCH UNIT ON 3 SECONDS BEFORE THE EVEN MINUTE.	
*1 A	03:
60 A	11:
55 A	12:
1 A	13:
8 A	21:
50 A	22:
2 A	23:
0 A	31:
55 A	32:
8 A	33:
18 A	41:
*2 A	03:
0 A	11:
*3 A	03:
0 A	11:
*4 A	11:
3 A	12:
8 A	13:
0 A	21:
7 A	22:
1 A	23:
0 A	31:
0 A	32:
0 A	33:
0 A	41:
0 A	42:
0 A	43:

KEY IN	DISPLAY
0 A	51:
0 A	52:
0 A	53:
0 A	61:
0 A	62:
0 A	63:
0 A	71:
0 A	72:
0 A	73:
0 A	81:
6 A	82:
D01 A	83:
D31 A	91:
0 A	92:
0 A	93:
0 A	
*5 A	
JULIAN DATA A	EX 38
HOUR A	EX 12
MINUTE A	EX 34
START HOUR A	EX 12

TO BEGIN LOGGING ALWAYS PRESS --

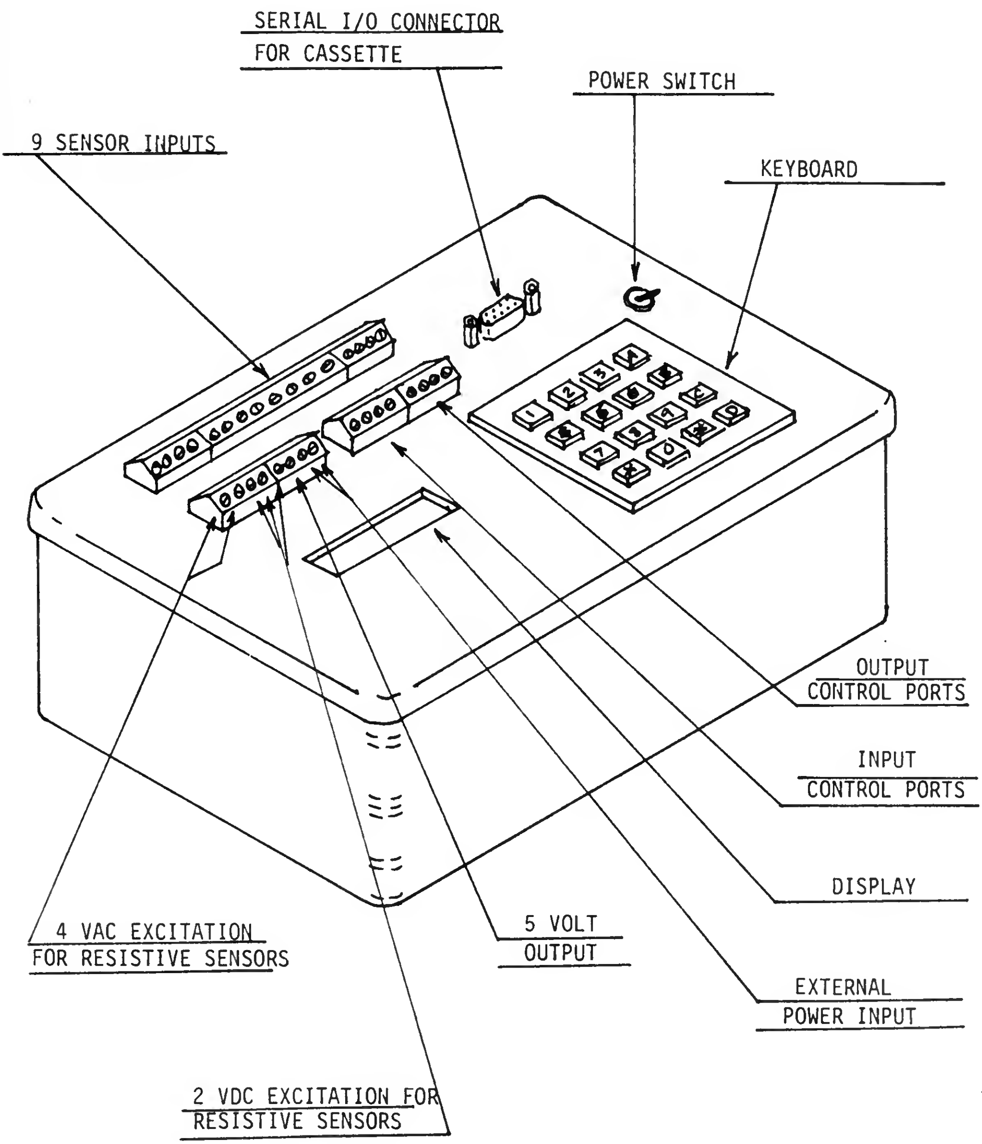
*0

---

*6 A BATTERY CHECK

9.5 VOLTS MIN.

CAMPBELL CR-21 MICROLOGGER

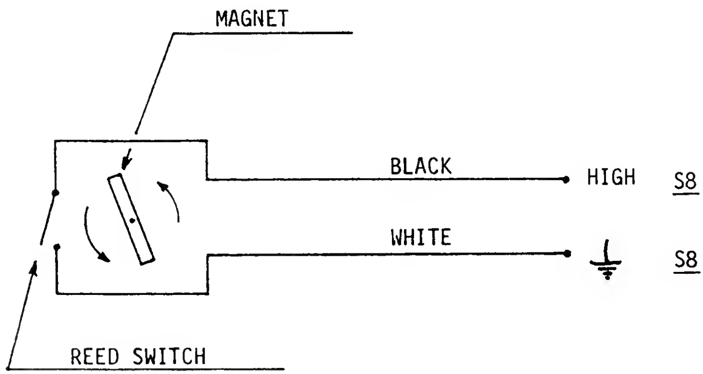


MET ONE-MODEL 014A WIND SPEED SENSOR

The Met One 014A Wind Speed Sensor uses an aluminum 3-cup anemometer assembly and simple magnet-reed switch assembly to produce a series of contact closures whose frequency is proportional to wind speed.

Performance Characteristics

Maximum Operating Range	0 - 125 MPH
Starting Speed	1 MPH
Calibration Range	0 - 100 MPH
Accuracy	$\pm$ 1.5% or 0.25 MPH
Temperature Range	$-$ 45° to 185° F



Theory of Operation

The anemometer cup assembly consists of three aluminum cups mounted on a mounting hub. The shape and low weight of the cup arms are responsible for the fast response and accuracy of the sensor. The cup assembly is mechanically linked to the magnet by a stainless steel shaft which turns on precision-sealed ball bearings. The rotation of the magnet causes the reed switch contacts to open and close twice every revolution. The frequency of closures is linear from threshold to 100 MPH.

MET ONE -- MODEL 014 WIND SPEED SENSOR

TWO SWITCH CLOSURES PER REVOLUTION

WIND VELOCITY (MPH)	RPS	RPM	F(HZ)	SWITCH CLOS/MIN
10	2.52	151.2	5.03	301.8
20	5.31	318.6	10.63	637.2
30	8.11	486.6	16.21	972.6
40	10.90	654.6	21.80	1,308.0
50	13.70	822.0	27.39	1,643.4
60	16.49	989.4	32.98	1,978.8
70	19.29	1,157.4	38.56	2,313.6
80	22.08	1,324.8	44.15	2,649.0
90	24.88	1,660.2	55.33	3,319.8

COUNTS/MIN X 0.01 + 0.31 = BIN NO.

EXAMPLE:
10 MPH = (301.8) 0.01 + 0.31 = 3.328
12 MPH = (369.6) 0.01 + 0.31 = 4.006
20 MPH = (637.2) 0.01 + 0.31 = 6.682
60 MPH = (1,978.8) 0.01 + 0.31 = 20.098

EACH BIN = 3 MPH EXAMPLE: 0 - 3 MPH = BIN NO. 1
3 - 6 MPH = BIN NO. 2

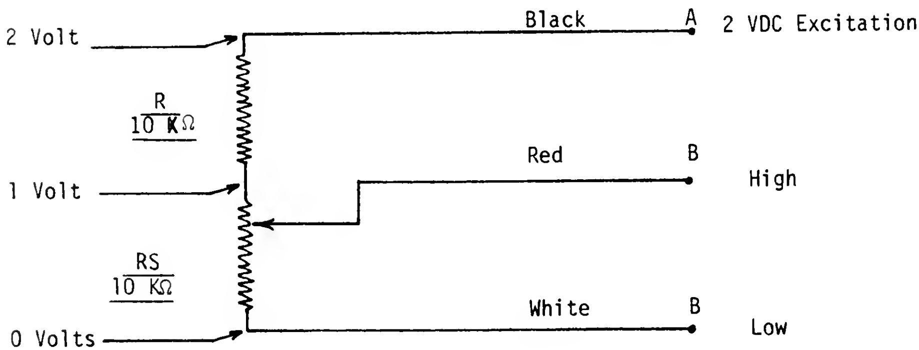
20 BINS FROM 0 to 60 MPH

MET ONE-MODEL 024 WIND DIRECTION SENSOR

The Met One 024 Wind Direction Sensor uses a lightweight air-foil vane mounted on a stainless steel shaft. This shaft connects to a potentiometer to produce a voltage output that varies proportional to wind direction.

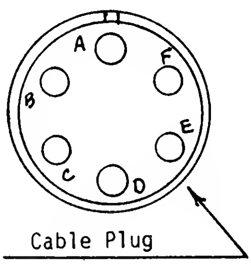
Performance Characteristics

Azimuth	Electrical 0-360° Mechanical 0-360°
Threshold	1.0 MPH
Linearity	$\pm$ 1/2% of Full Scale
Accuracy	$\pm$ 5°
Damping Ratio	0.4
Delay Distance	Less than 3 Feet



V_{High} = 2 X RS/(R + RS)

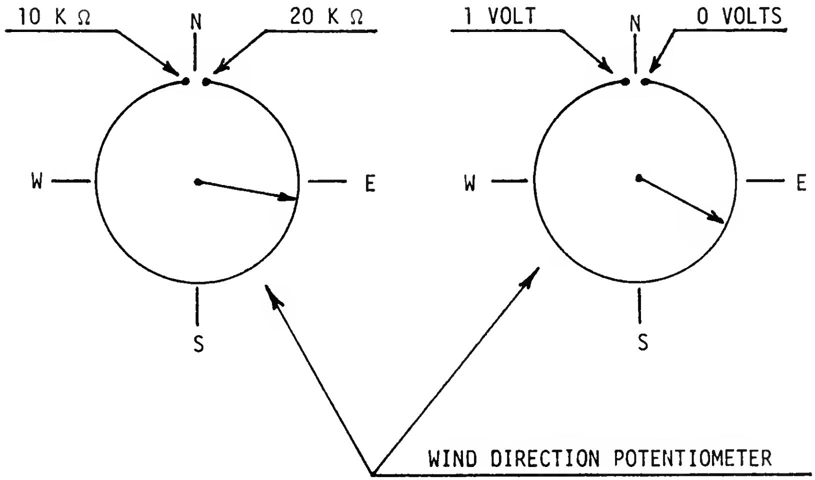
R = Current Limiting Resistor



Cable Plug

A ∿ Black Wire
B ∿ White Wire
C ∿ Red Wire

MET ONE-MODEL 024 WIND DIRECTION SENSOR



Theory of Operation

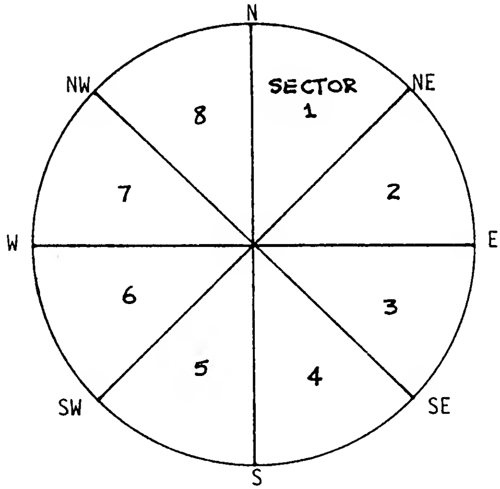
The Model 024 utilizes a lightweight vane which is free to rotate through 360° in the horizontal plane. The vane is directly coupled to a micro torque potentiometer. The varying wind direction causes the potentiometer's output to vary accordingly.

Example: Wind from the east will give 0.25 volt output.

High and low connections to channel S1 on the micrologger.

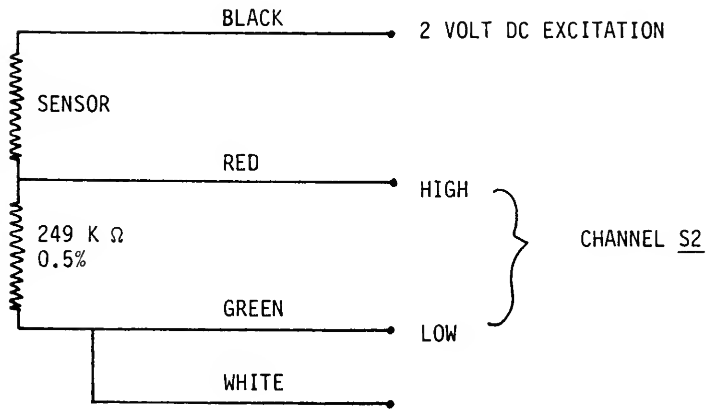
WIND DIRECTION HISTOGRAM

INPUT PROGRAM NO. 3
MULTIPLIER 8
OFFSET 0



SECTOR NO.	VOLTAGE
1	0 - .125
2	.125 - .250
3	.250 - .375
4	.375 - .500
5	.500 - .625
6	.625 - .750
7	.750 - .875
8	.875 - 1.000

CAMPBELL SCI. MODEL 101 THERMISTOR



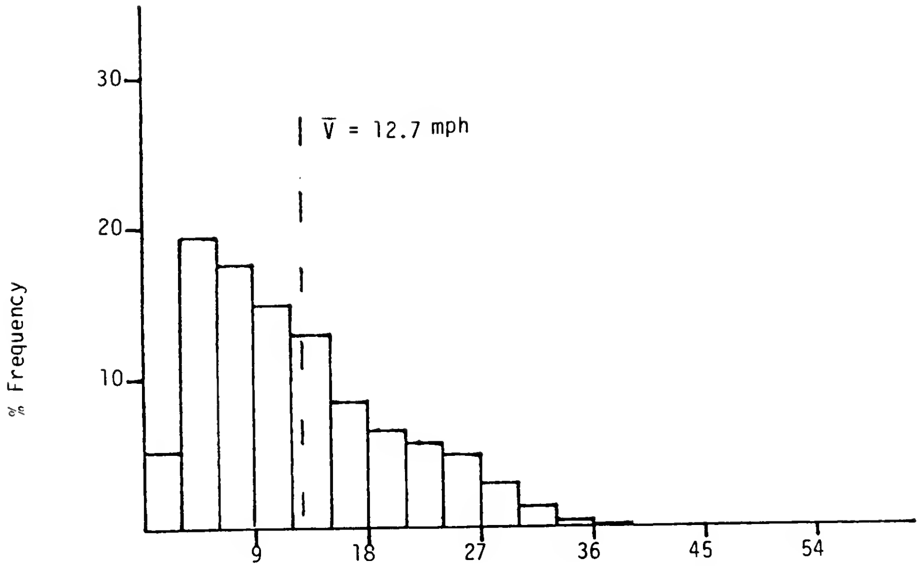
THE MODEL 101 THERMISTOR PROBE IS CONNECTED TO CHANNEL S2 OF THE MICROPROCESSOR.

<u>Performance Characteristics</u>

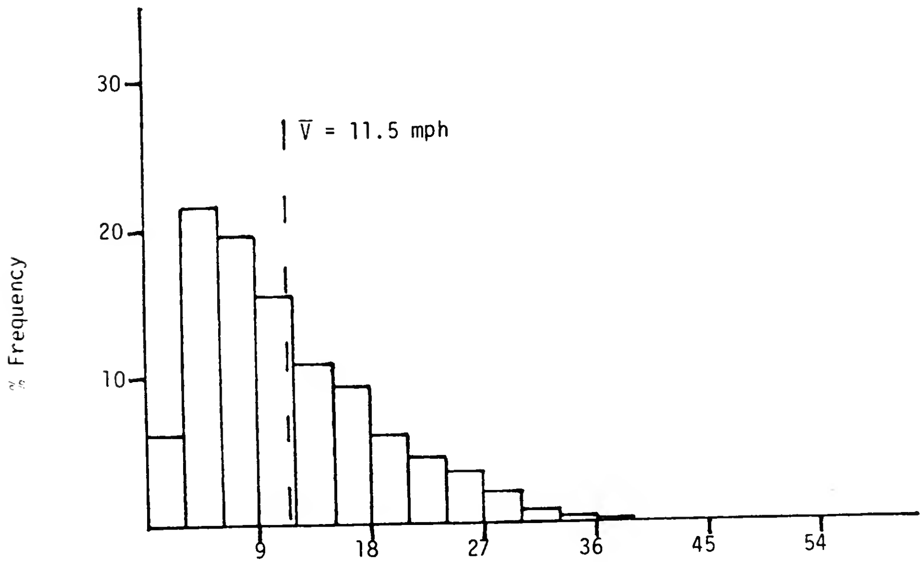
SENSOR TYPE:	Thermistor Bead 100K OHMS at 25°C
OUTPUT:	-35.0°C to 55.0° ± 0.2 Deg C.
MULTIPLIER:	1.000 for Deg C. 1.800 for Deg F.
OFFSET:	0 for Deg C. 32 for Deg F.
SENSOR HOOKUP:	See Diagram Above.

APPENDIX B

FREQUENCY DISTRIBUTION DATA BY THE MONTH



Wind Speed (MPH) March 1980 -- Whitehall



Wind Speed (MPH) April 1980 -- Whitehall

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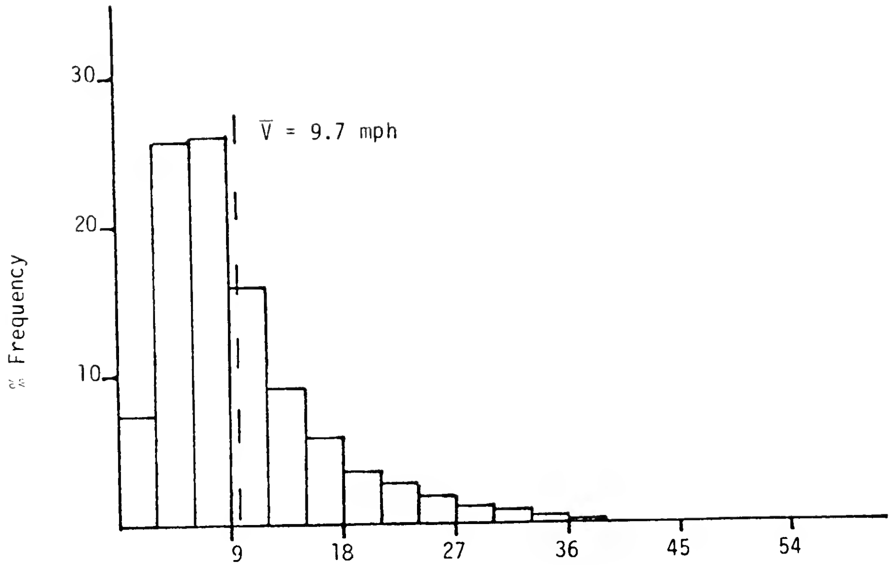
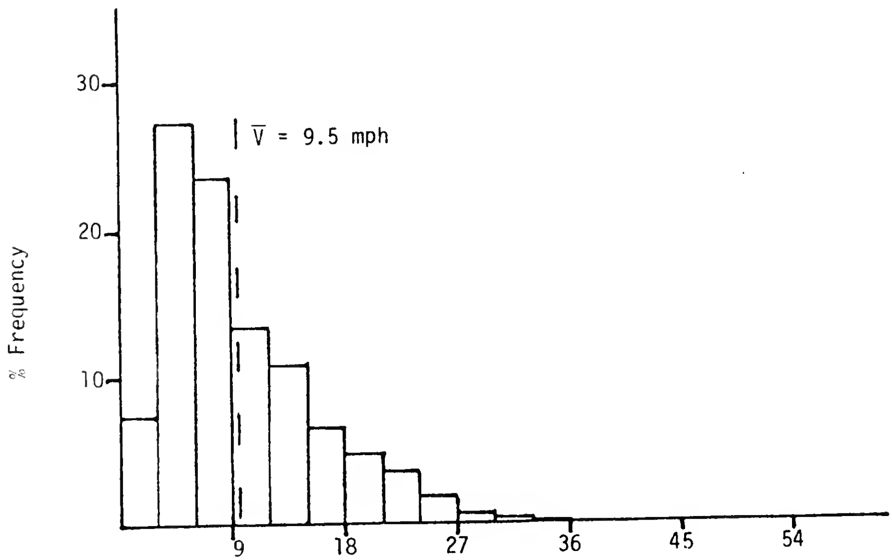
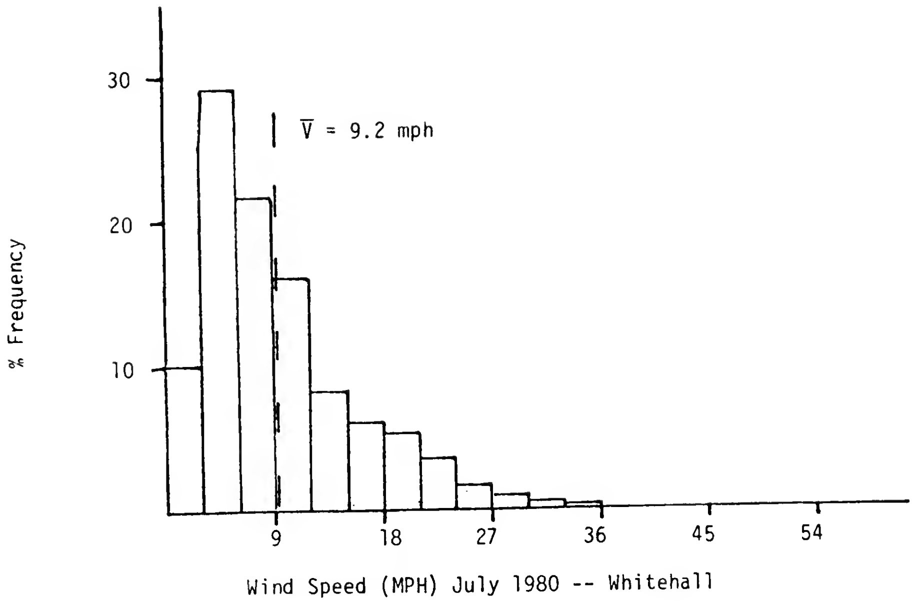


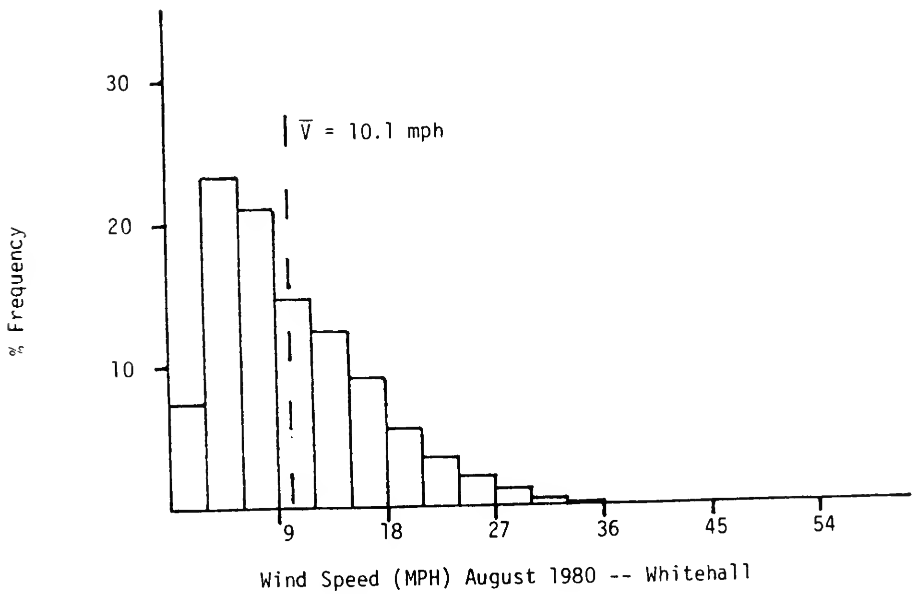
Wind Speed (MPH) May 1980 -- Whitehall



Wind Speed (MPH) June 1980 -- Whitehall

WIND SPEED FREQUENCY DISTRIBUTION GRAPH





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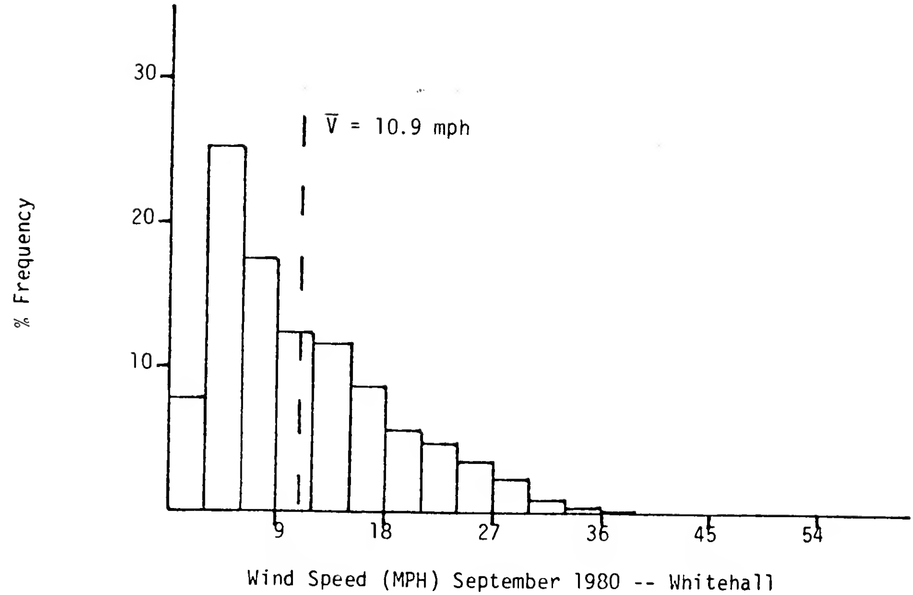

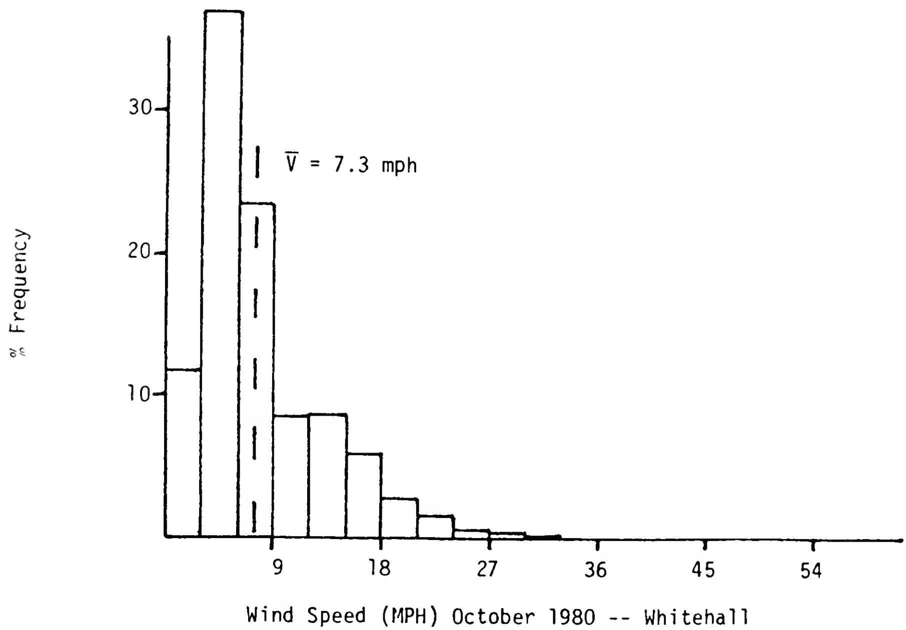

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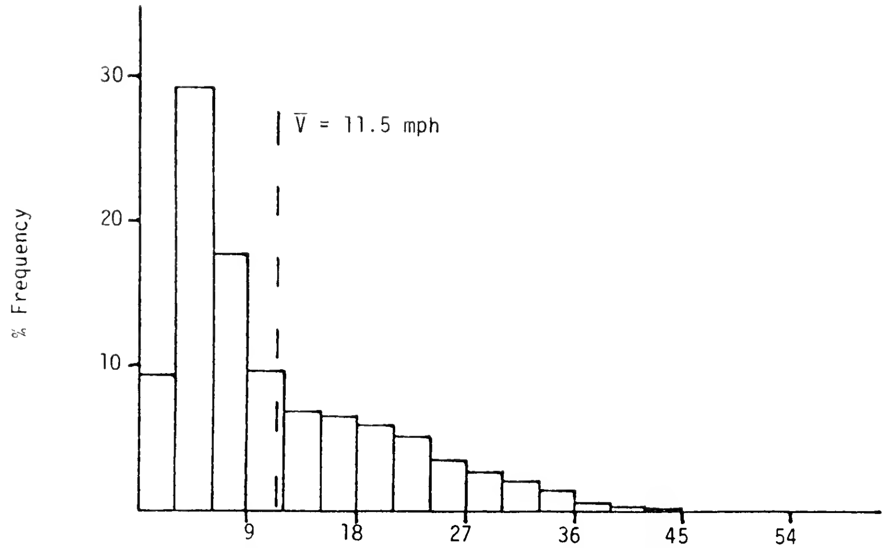
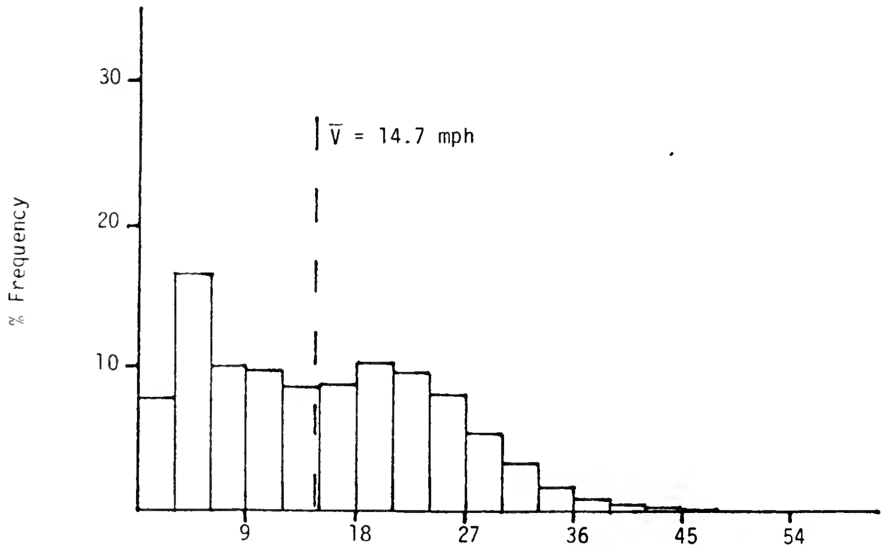


Wind Speed (MPH) November 1980 -- Whitehall



Wind Speed (MPH) December 1980 -- Whitehall

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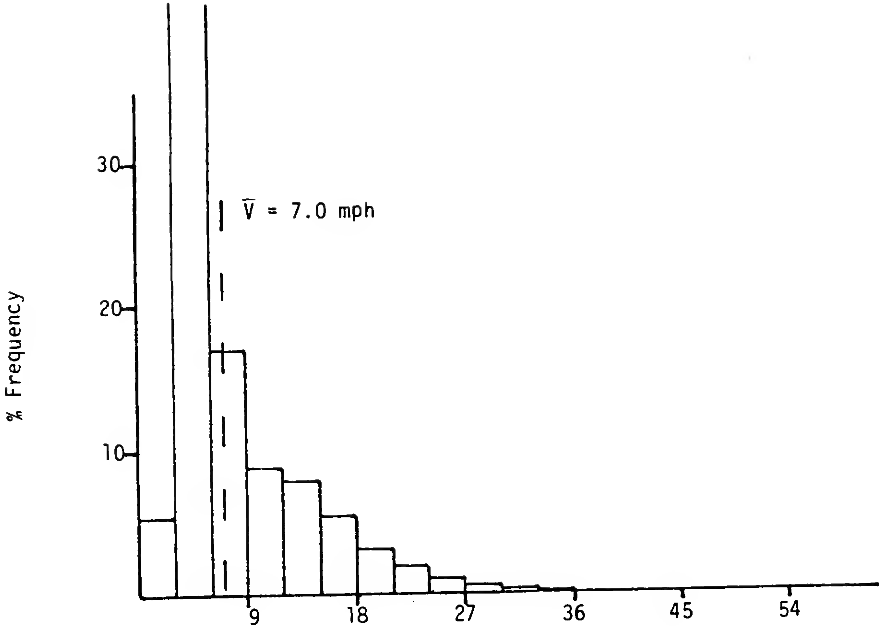
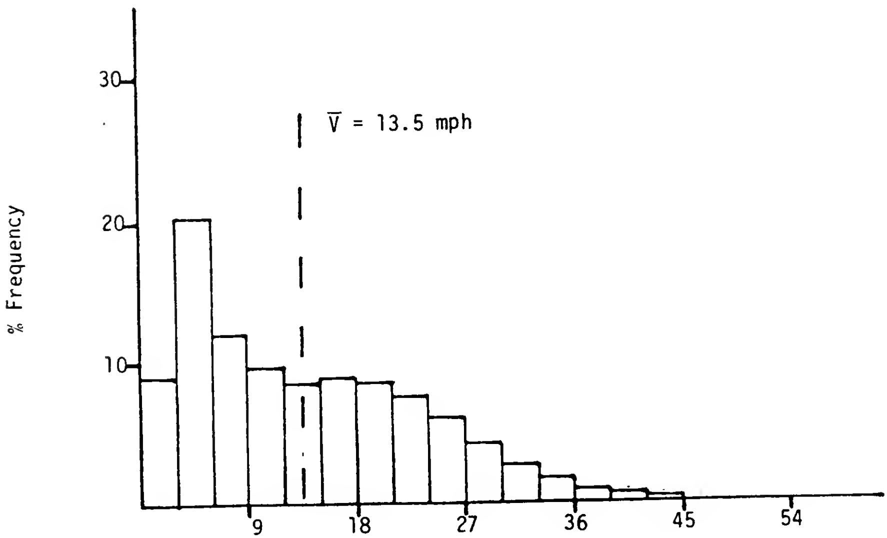


Wind Speed (MPH) January 1981 -- Whitehall



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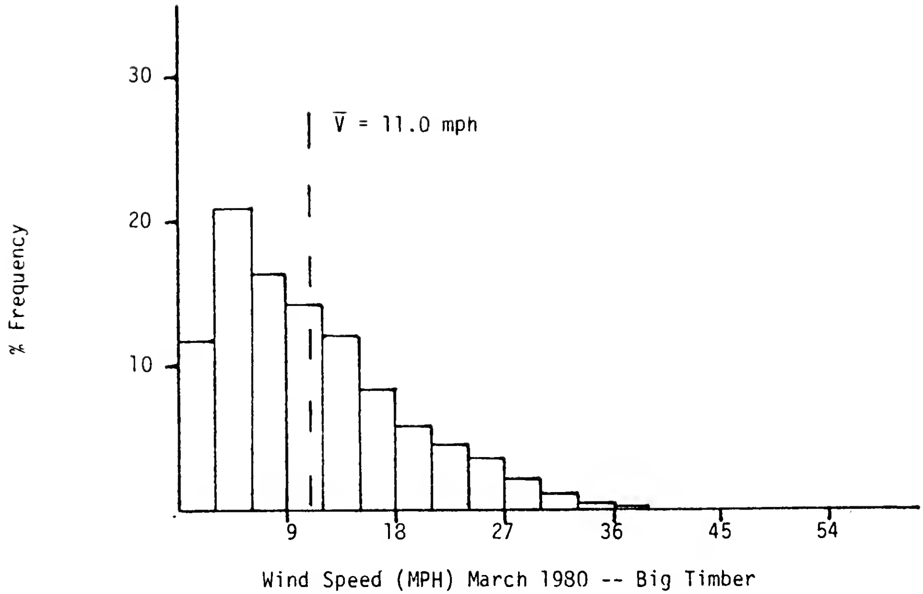

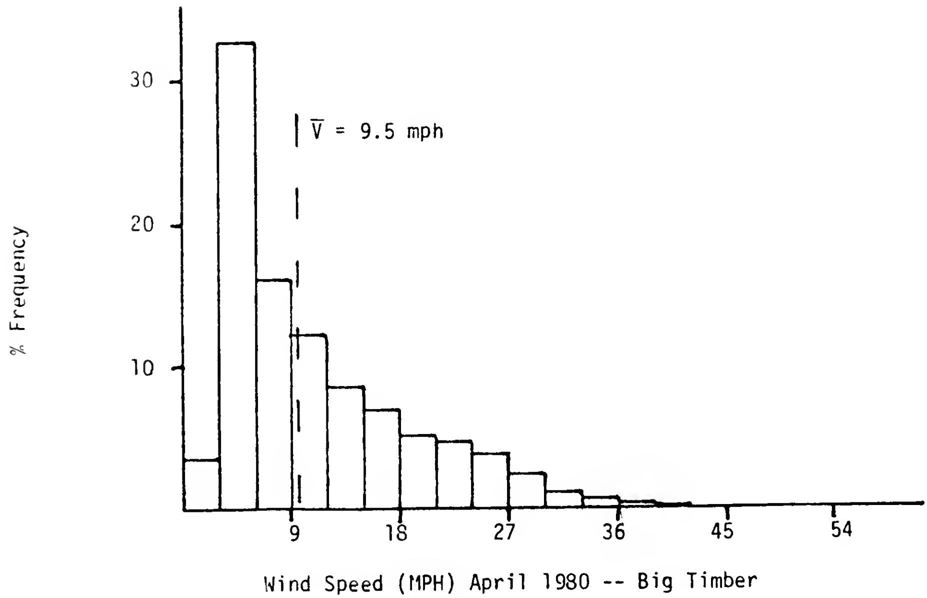

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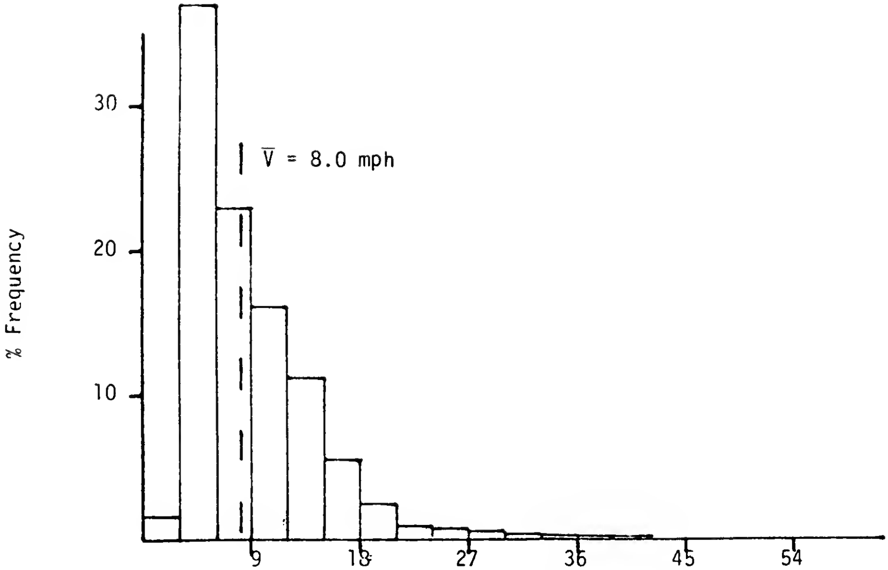
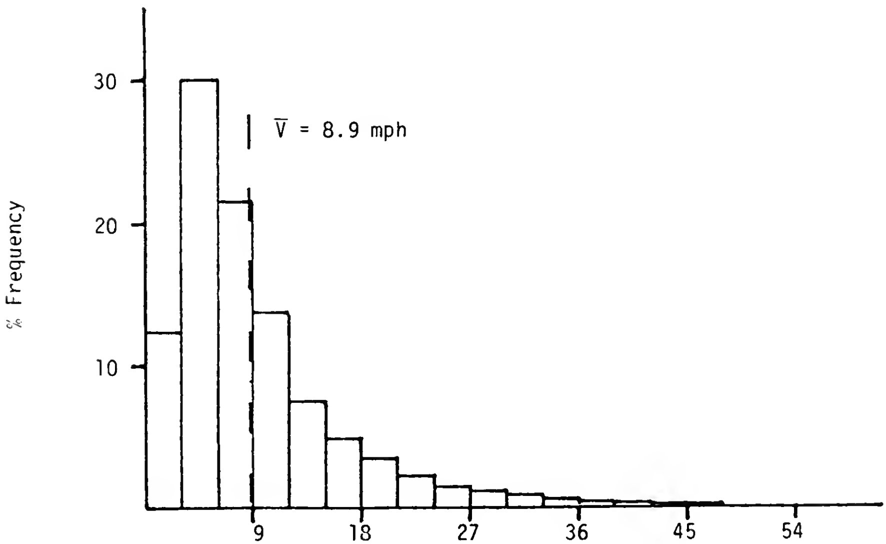


Wind Speed (MPH) May 1980 -- Big Timber



Wind Speed (MPH) June 1980 -- Big Timber

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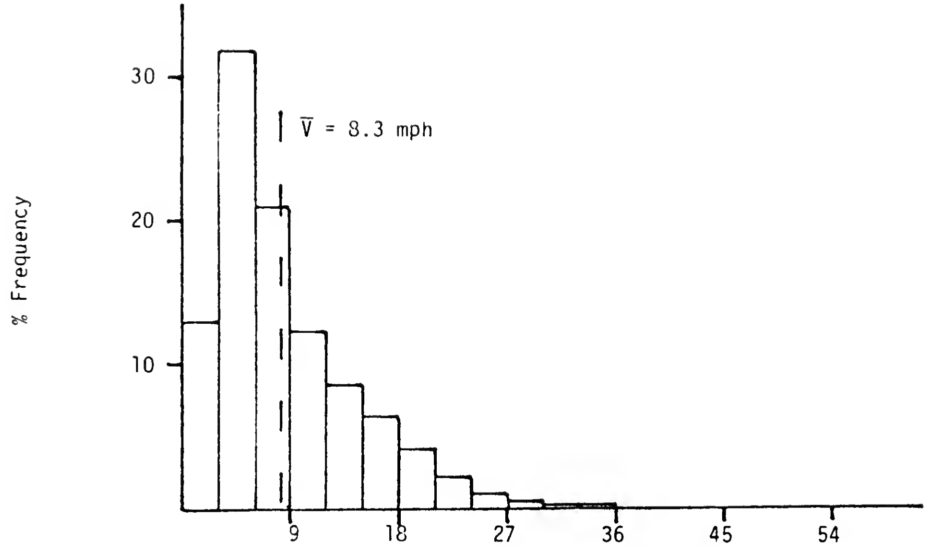
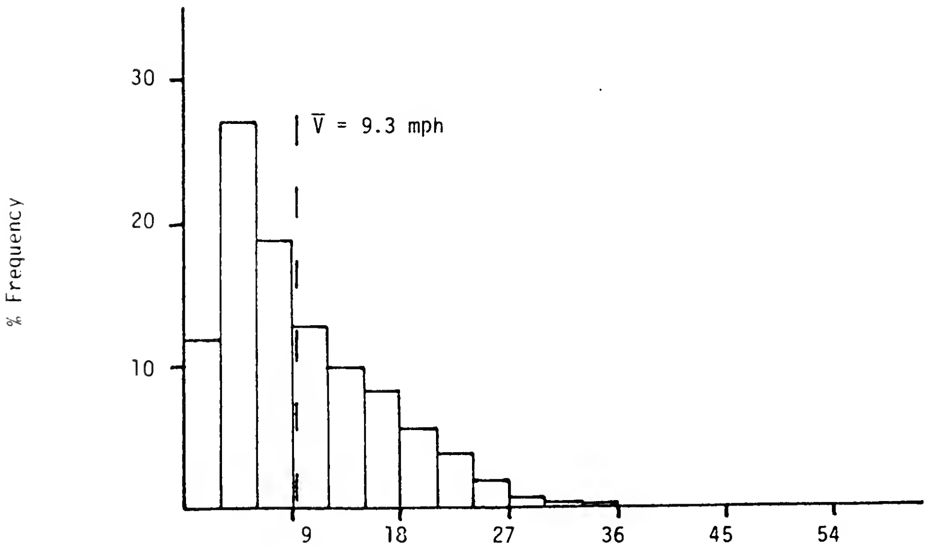


Wind Speed (MPH) July 1980 -- Big Timber



Wind Speed (MPH) August 1980 -- Big Timber

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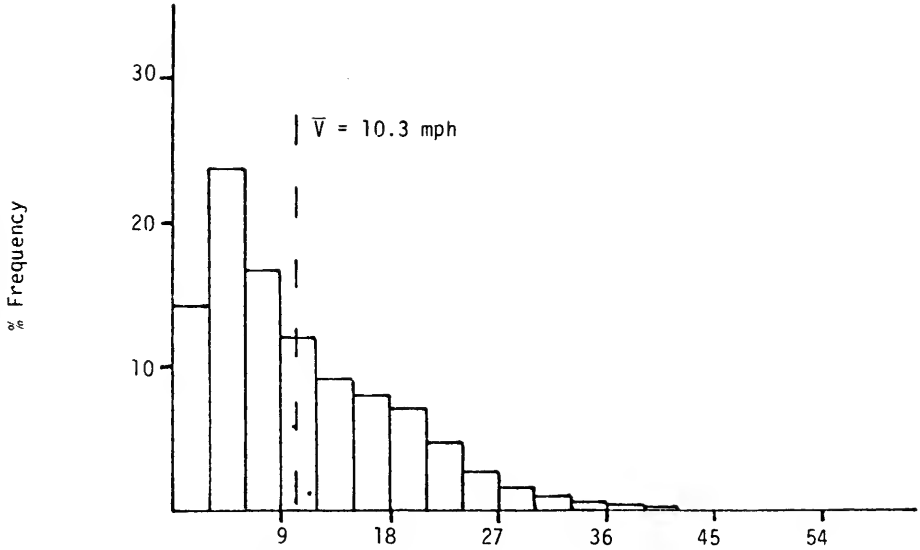

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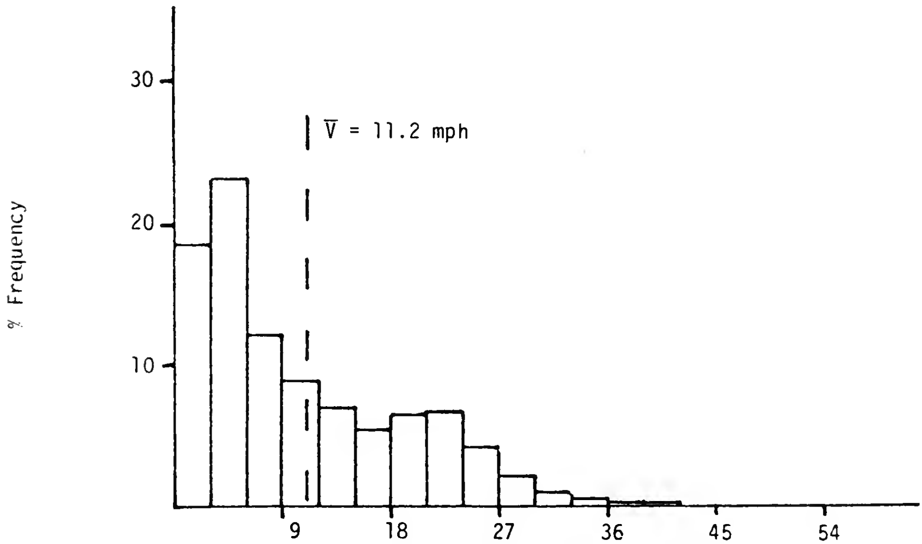
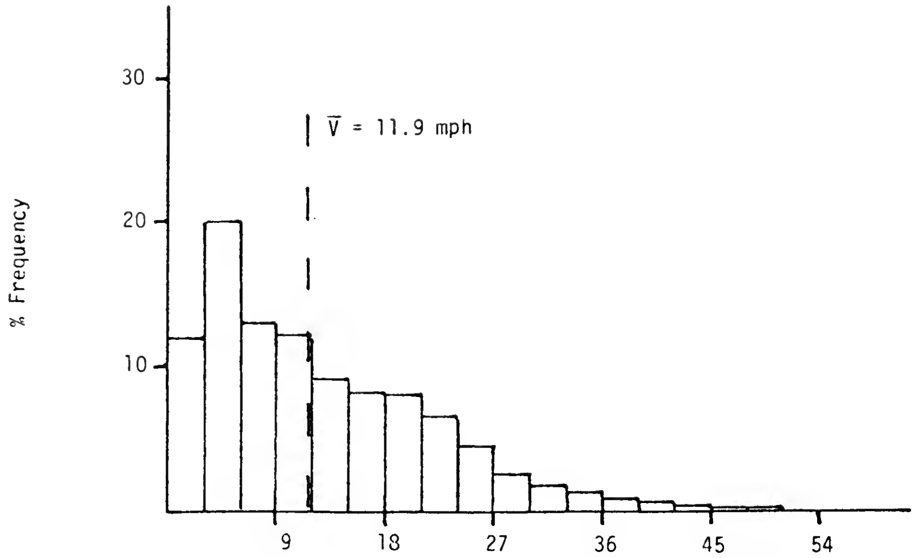
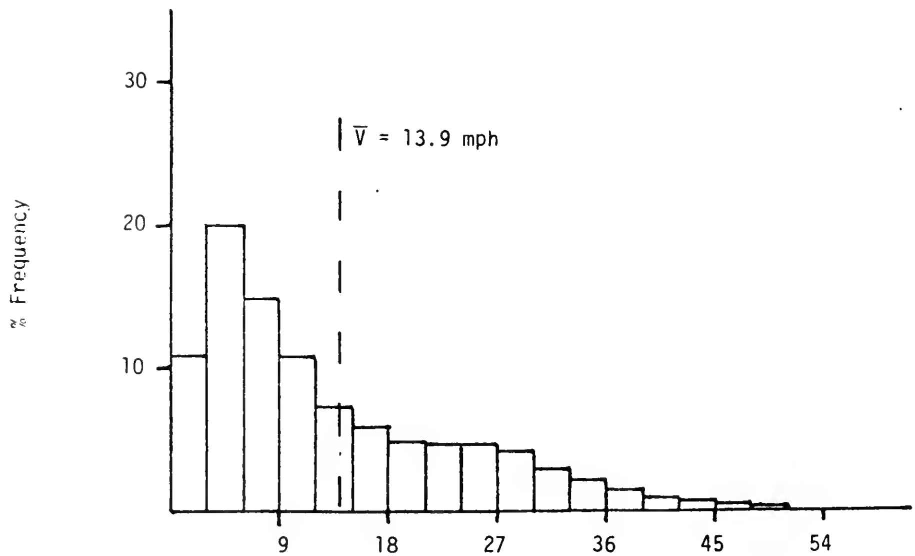


Wind Speed (MPH) October 1980 -- Big Timber

WIND SPEED FREQUENCY DISTRIBUTION GRAPH



Wind Speed (MPH) November 1980 -- Big Timber



Wind Speed (MPH) December 1980 -- Big Timber

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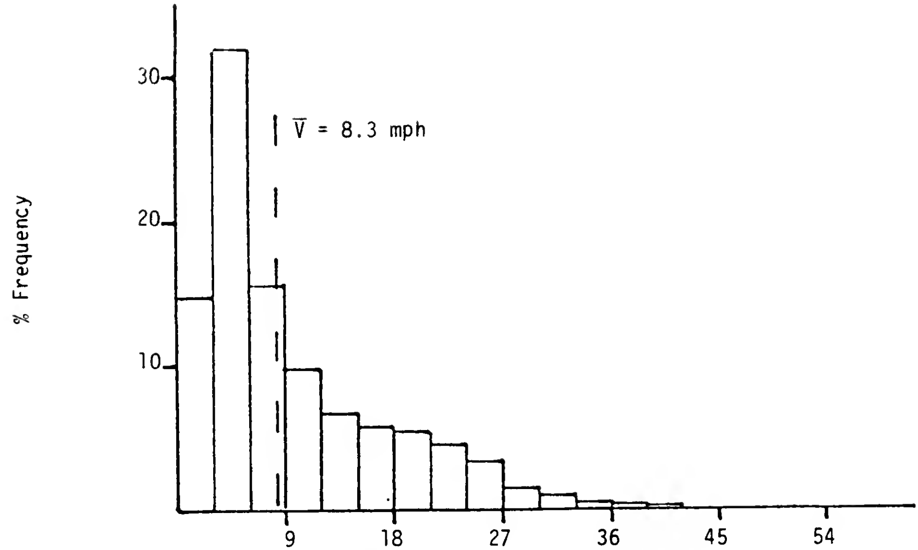
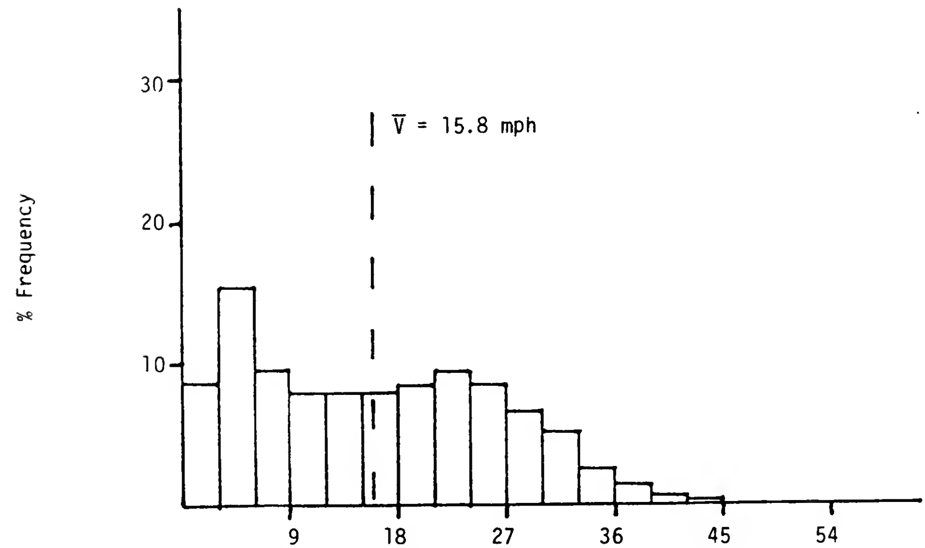
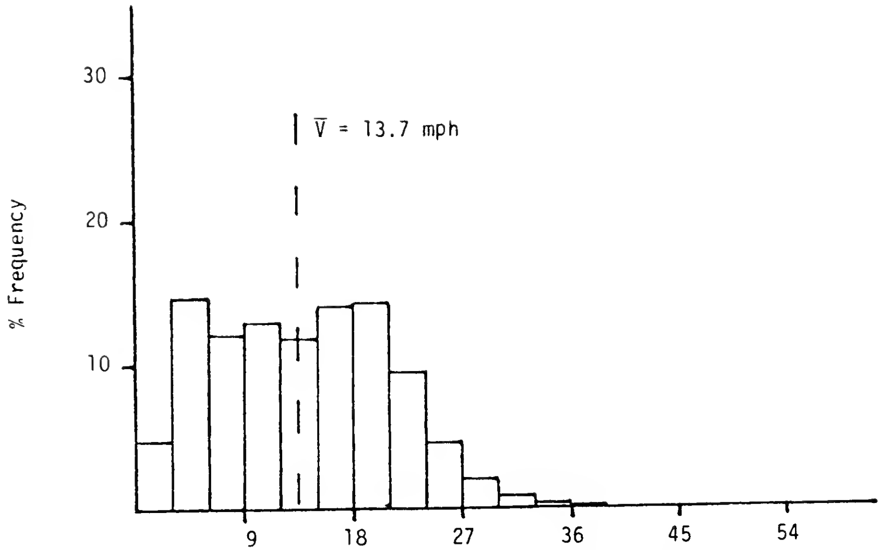


Wind Speed (MPH) January 1981 -- Big Timber

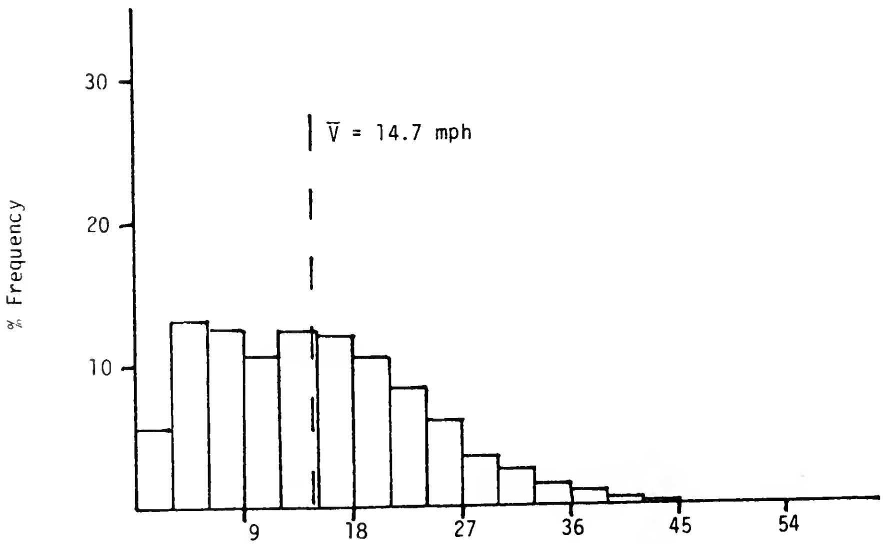


Wind Speed (MPH) February 1981 -- Big Timber

WIND SPEED FREQUENCY DISTRIBUTION GRAPH

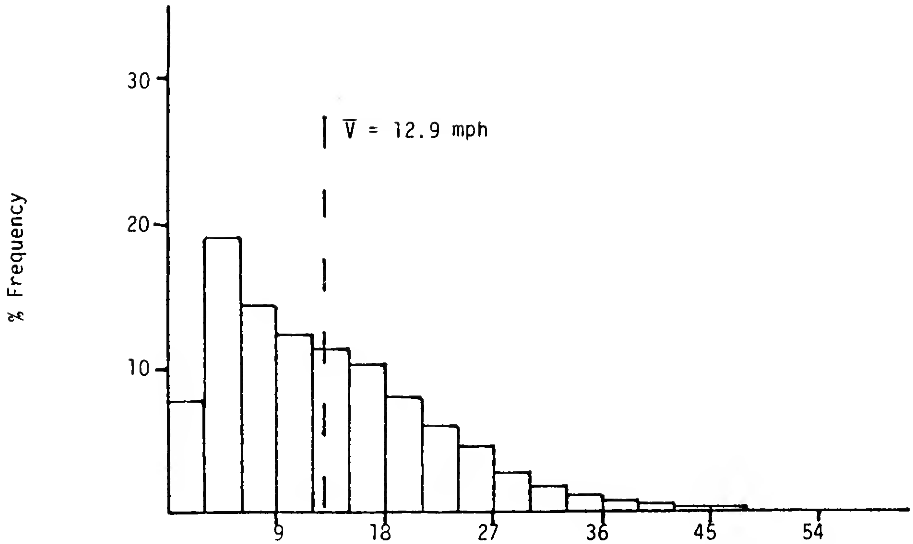


Wind Speed (MPH) March 1980 -- Livingston

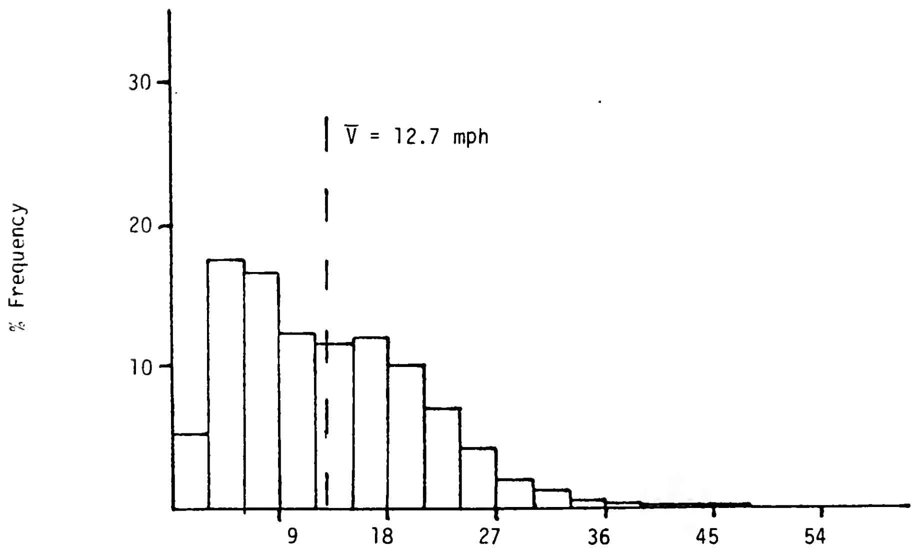


Wind Speed (MPH) April 1980 -- Livingston

WIND SPEED FREQUENCY DISTRIBUTION GRAPH



Wind Speed (MPH) May 1980 -- Livingston



Wind Speed (MPH) June 1980 -- Livingston

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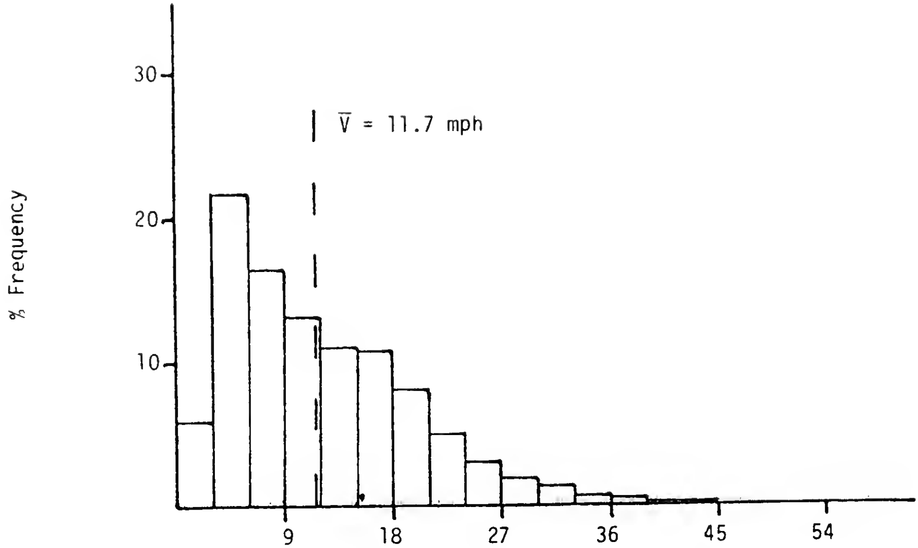
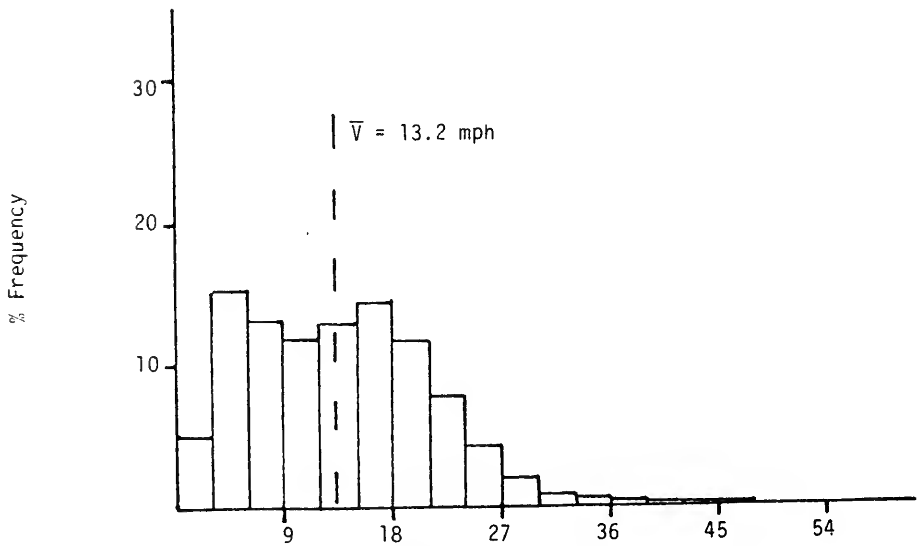


Wind Speed (MPH) July 1980 -- Livingsotn



Wind Speed (MPH) August 1980 -- Livingsotn

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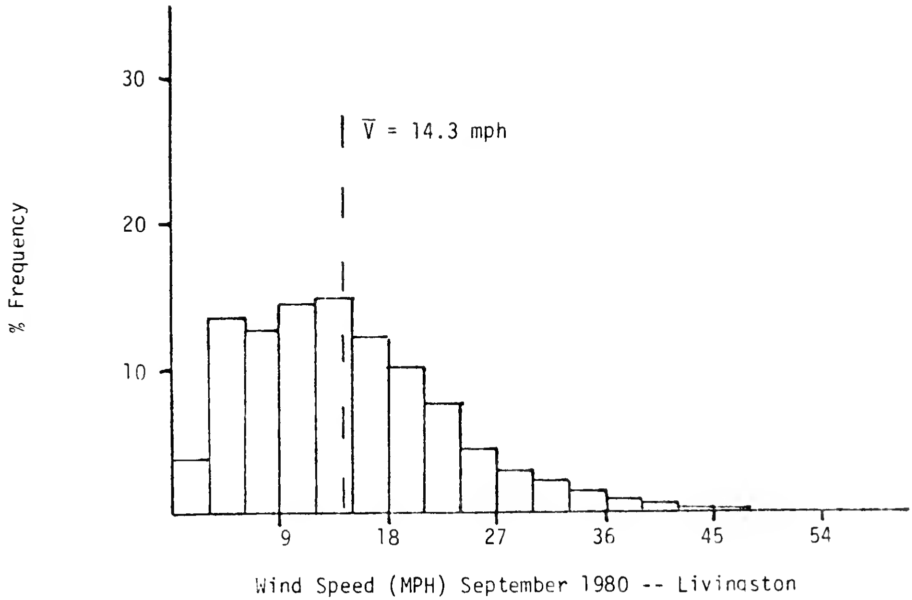

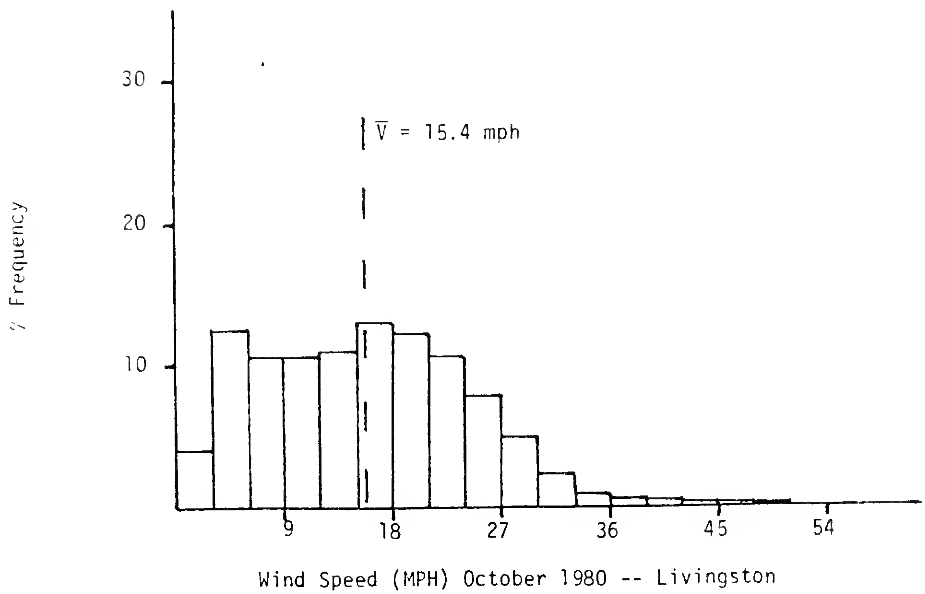

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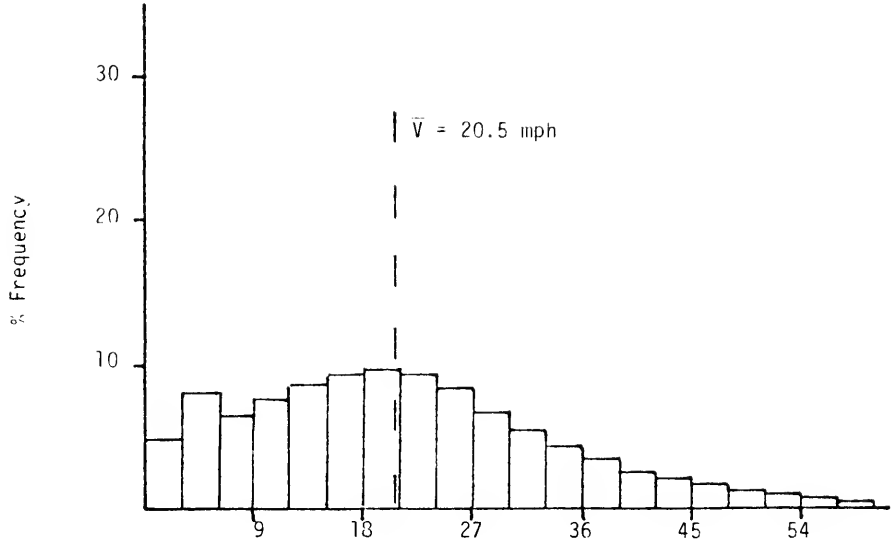
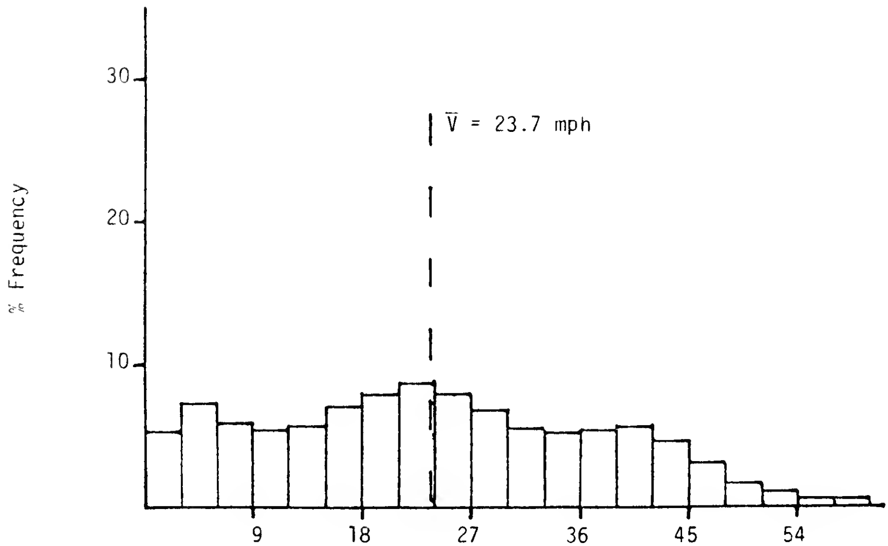
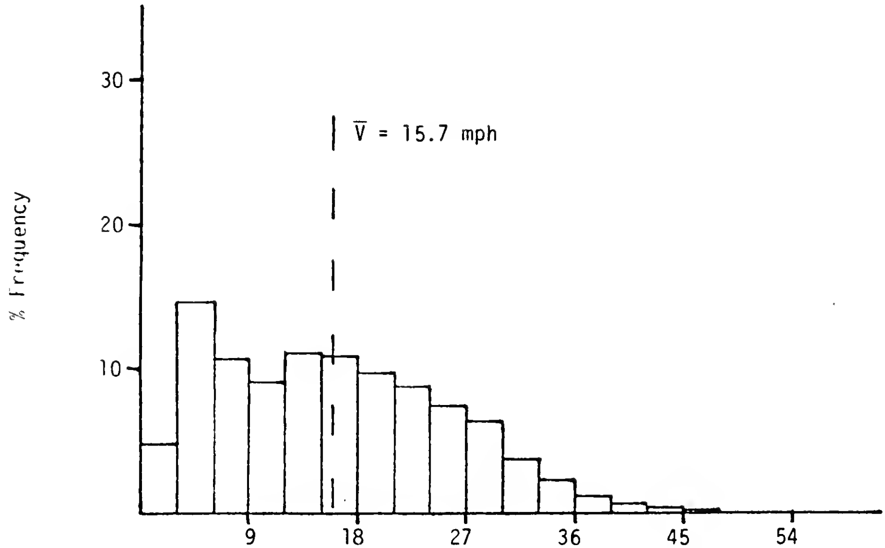


Wind Speed (MPH) November 1980 -- Livingston

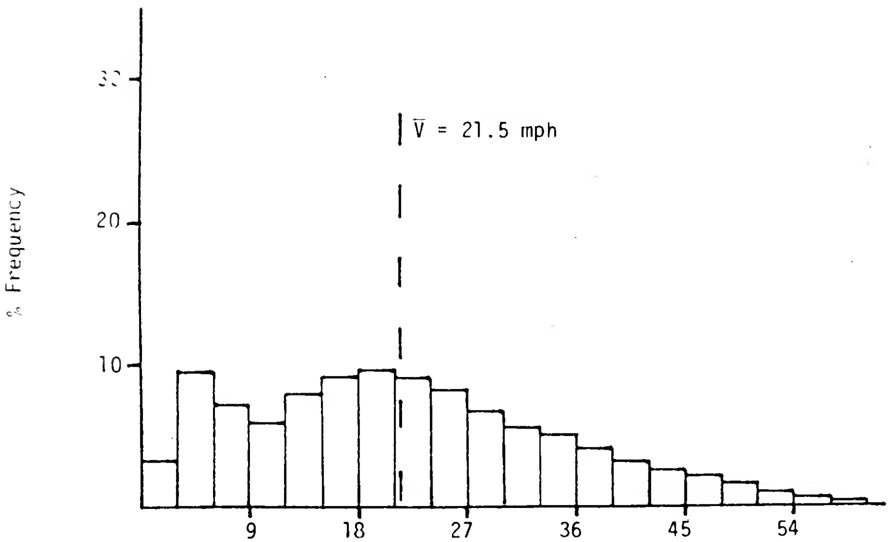


Wind Speed (MPH) December 1980 -- Livingston

WIND SPEED FREQUENCY DISTRIBUTION GRAPH



Wind Speed (MPH) January 1981 -- Livingston



Wind Speed (MPH) February 1981 -- Livingston

WIND SPEED FREQUENCY DISTRIBUTION GRAPH

APPENDIX C

PRINTED WIND DATA

(Separate Document)

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